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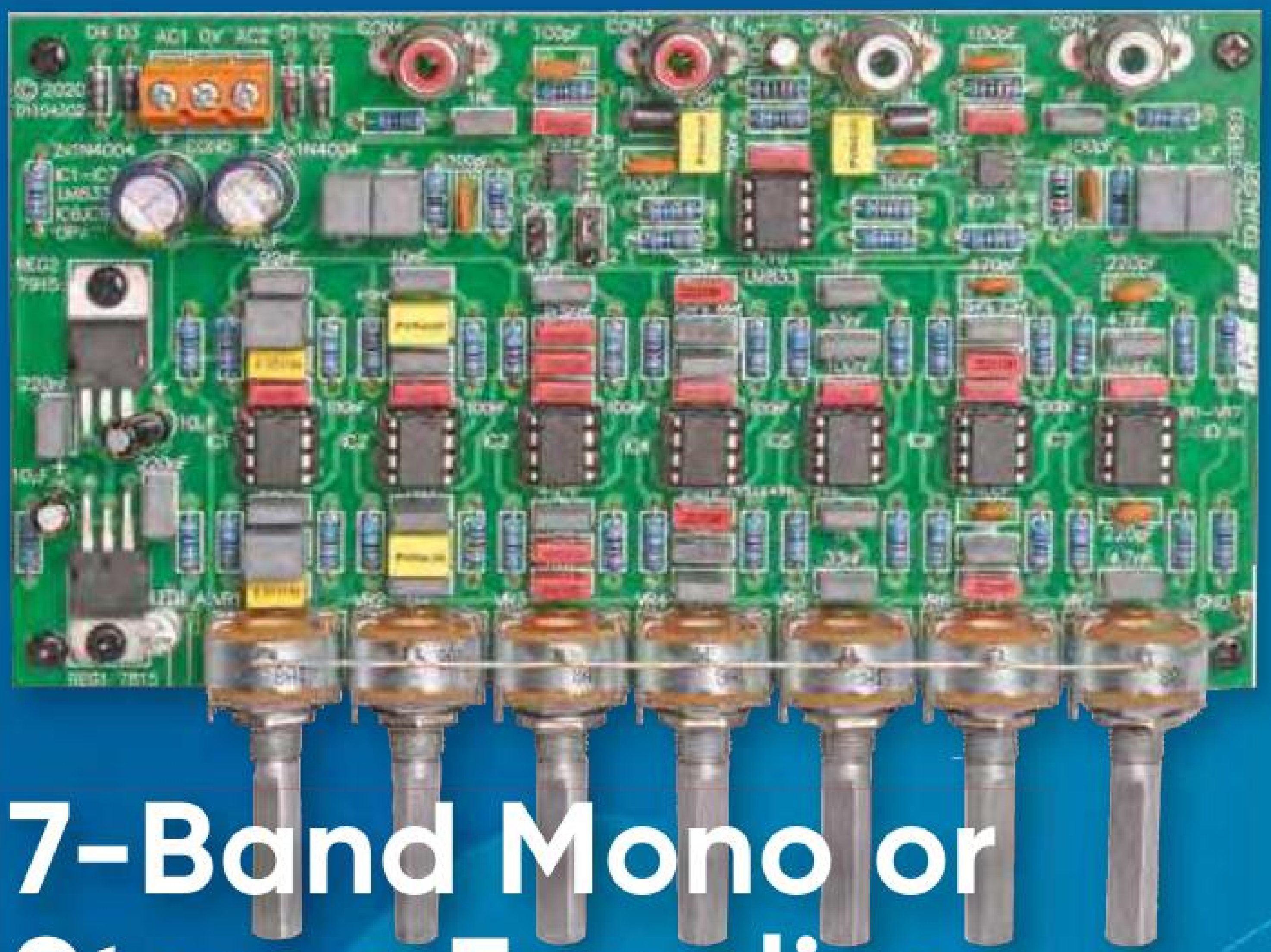

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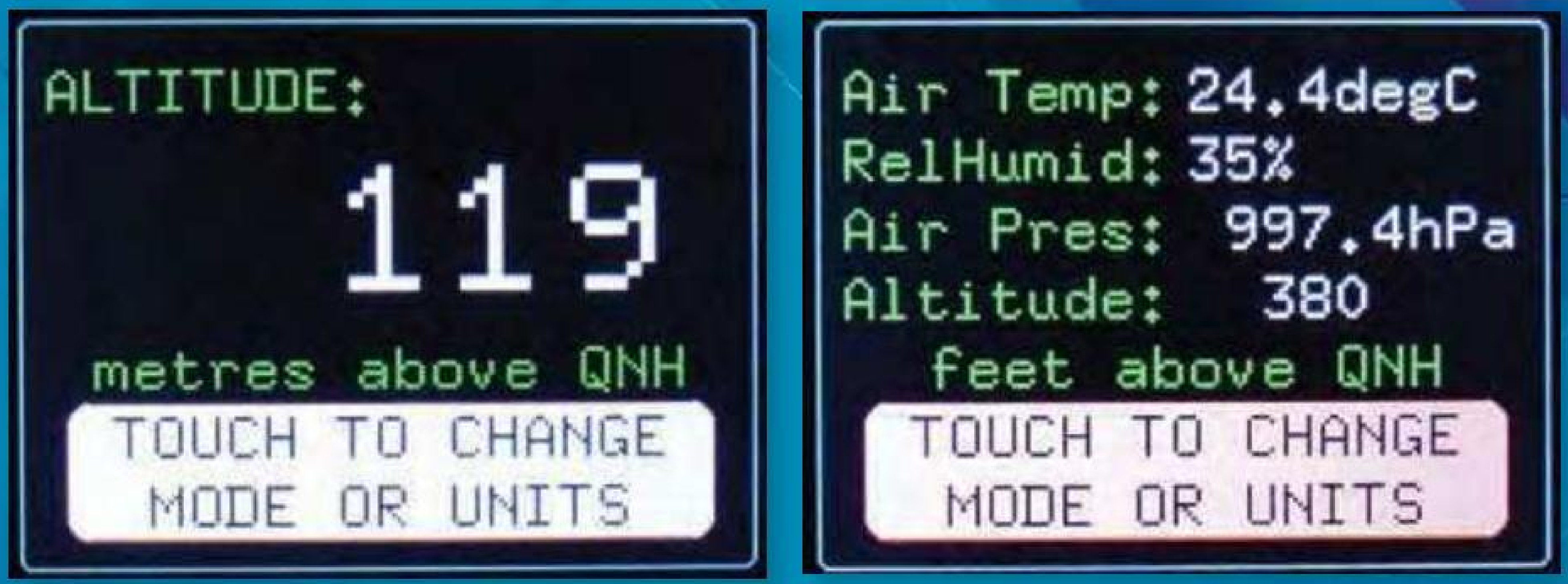

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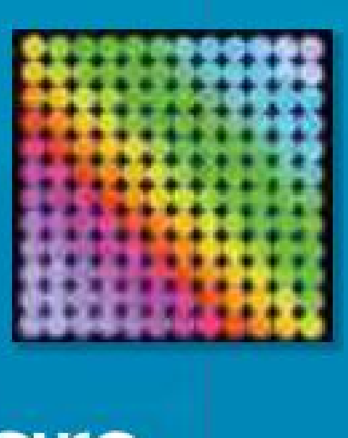

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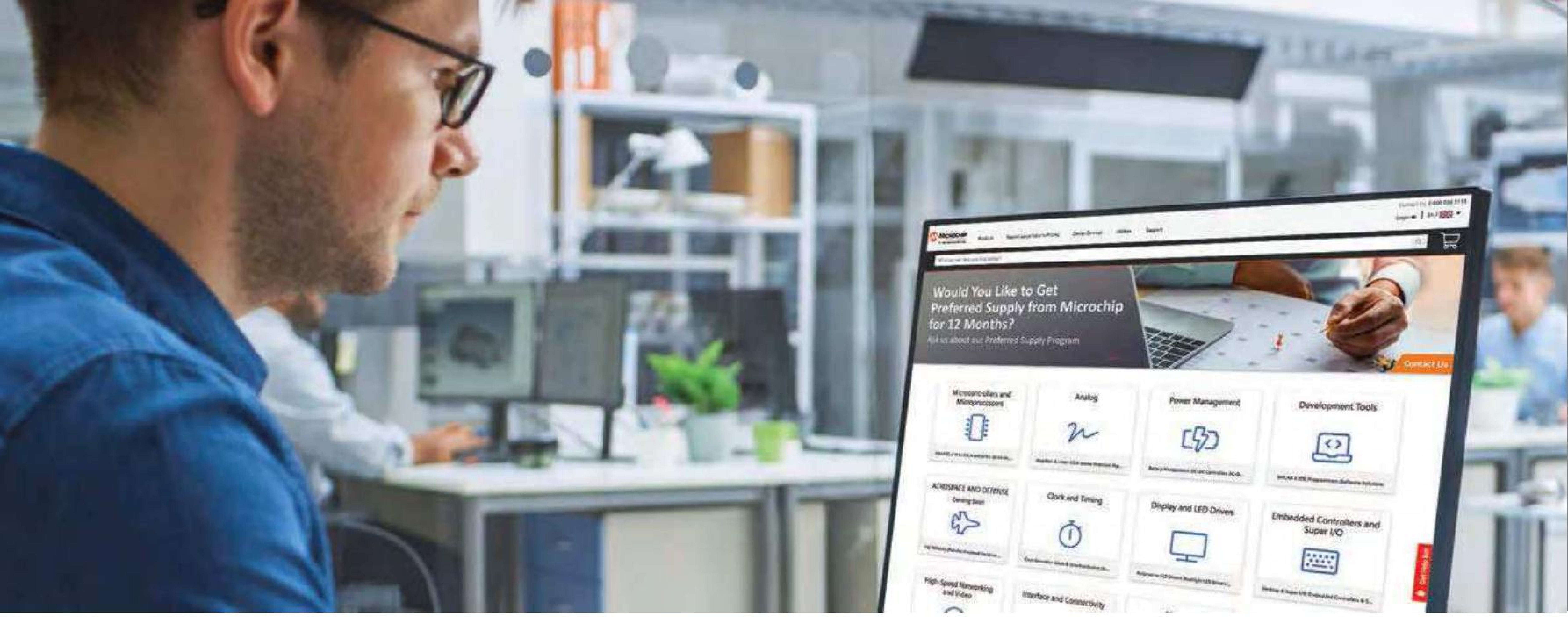
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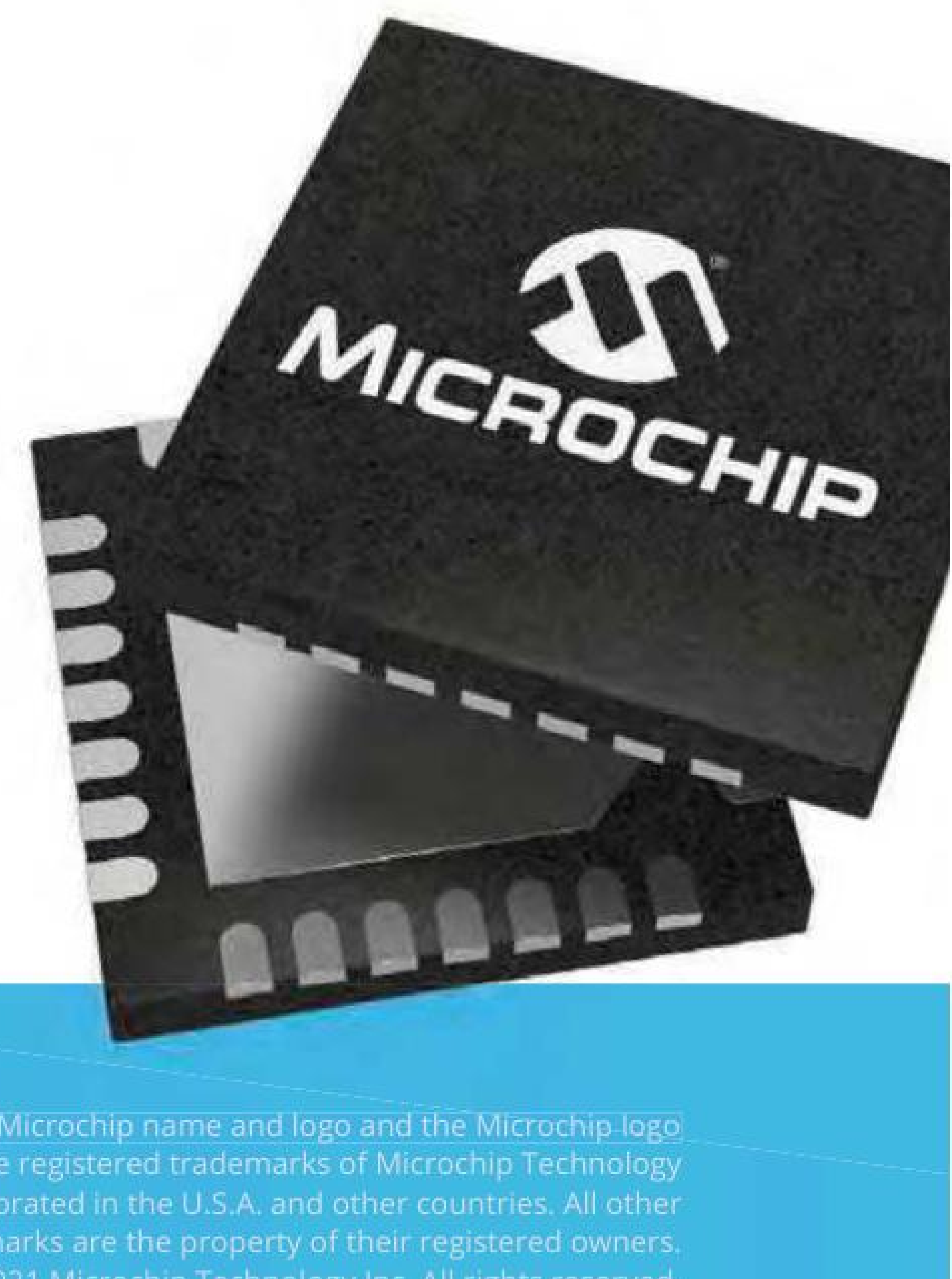

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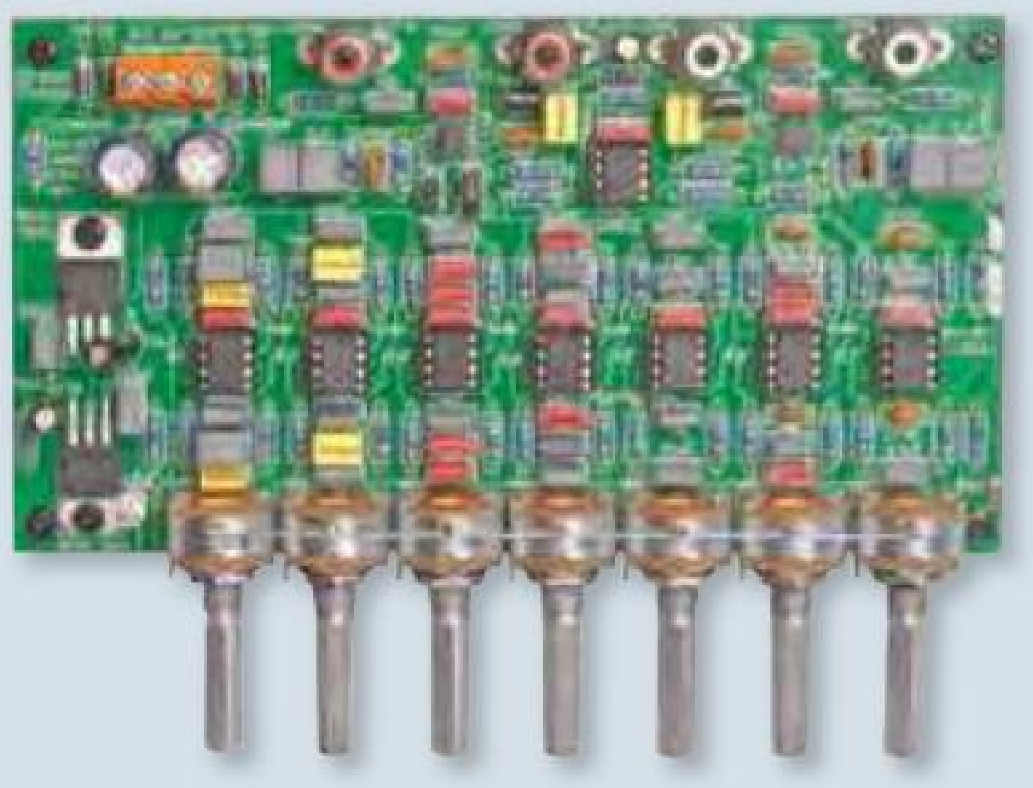

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The June 2021 issue of *Practical Electronics* will be published on Thursday, 6 May 2021 – see page 72.

WIRELESS FOR THE WARRIOR

by LOUIS MEULSTEE

THE DEFINITIVE TECHNICAL HISTORY OF RADIO COMMUNICATION EQUIPMENT IN THE BRITISH ARMY

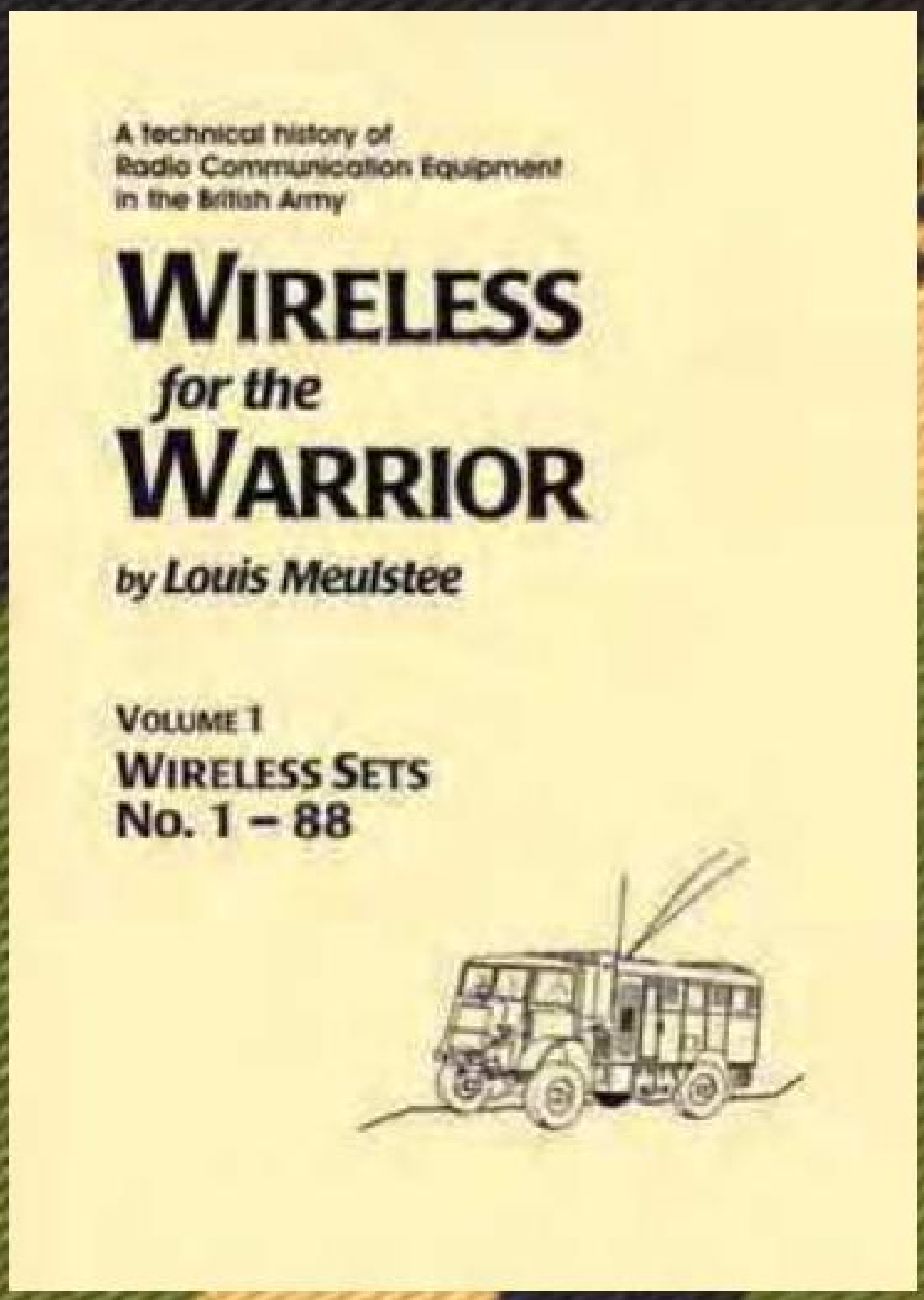
The *Wireless for the Warrior* books are a source of reference for the history and development of radio communication equipment used by the British Army from the very early days of wireless up to the 1960s.

The books are very detailed and include circuit diagrams, technical specifications and alignment data, technical development history, complete station lists and vehicle fitting instructions.

Volume 1 and *Volume 2* cover transmitters and transceivers used between 1932-1948. An era that starts with positive steps taken to formulate and develop a new series of wireless sets that offered great improvements over obsolete World War I pattern equipment. The other end of this timeframe saw the introduction of VHF FM and hermetically sealed equipment.

Volume 3 covers army receivers from 1932 to the late 1960s. The book not only describes receivers specifically designed for the British Army, but also the Royal Navy and RAF. Also covered: special receivers, direction finding receivers, Canadian and Australian Army receivers, commercial receivers adopted by the Army, and Army Welfare broadcast receivers.

Volume 4 covers clandestine, agent or 'spy' radio equipment, sets which were used by special forces, partisans, resistance, 'stay behind' organisations, Australian Coast Watchers and the diplomatic service. Plus, selected associated power sources, RDF and intercept receivers, bugs and radar beacons.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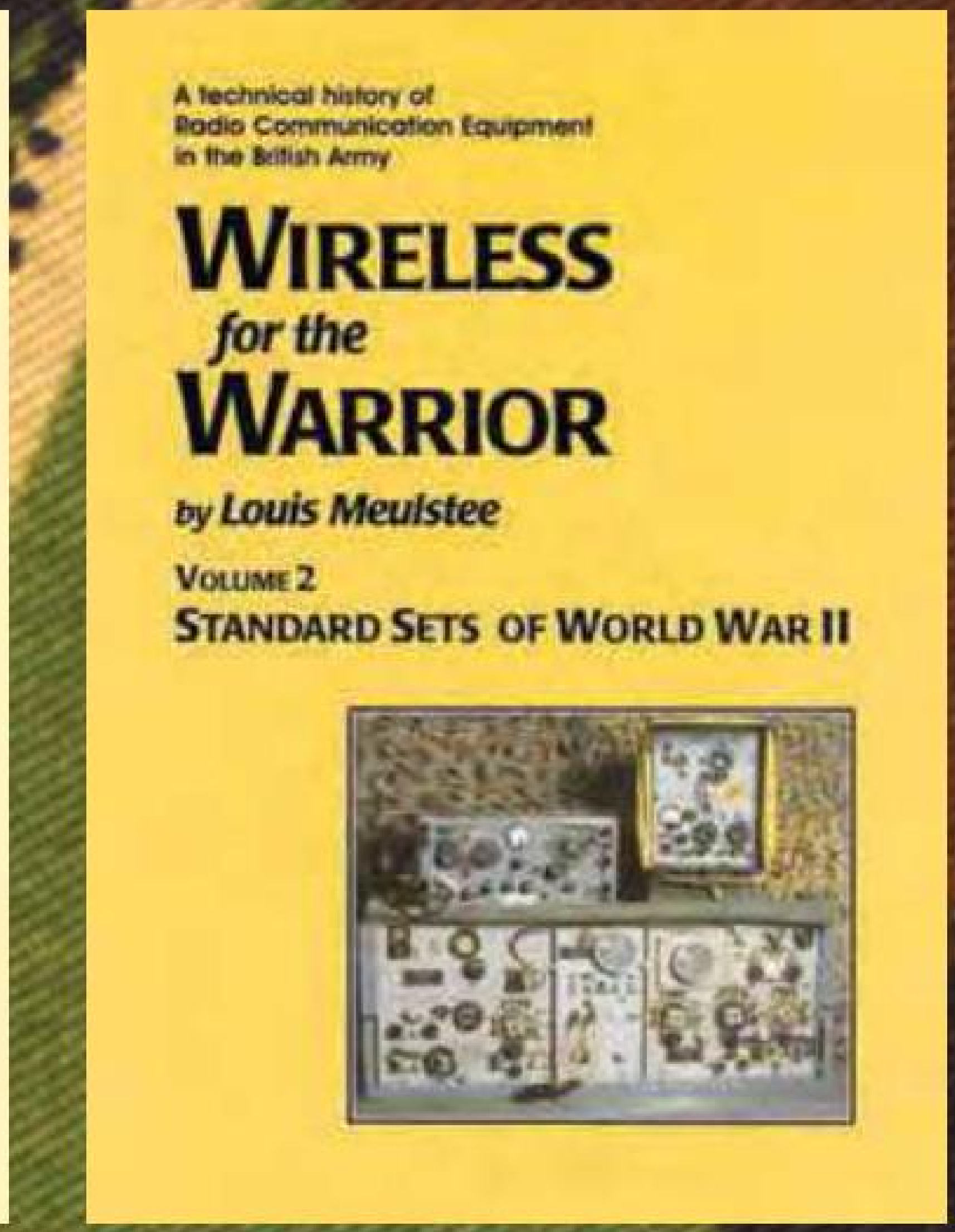
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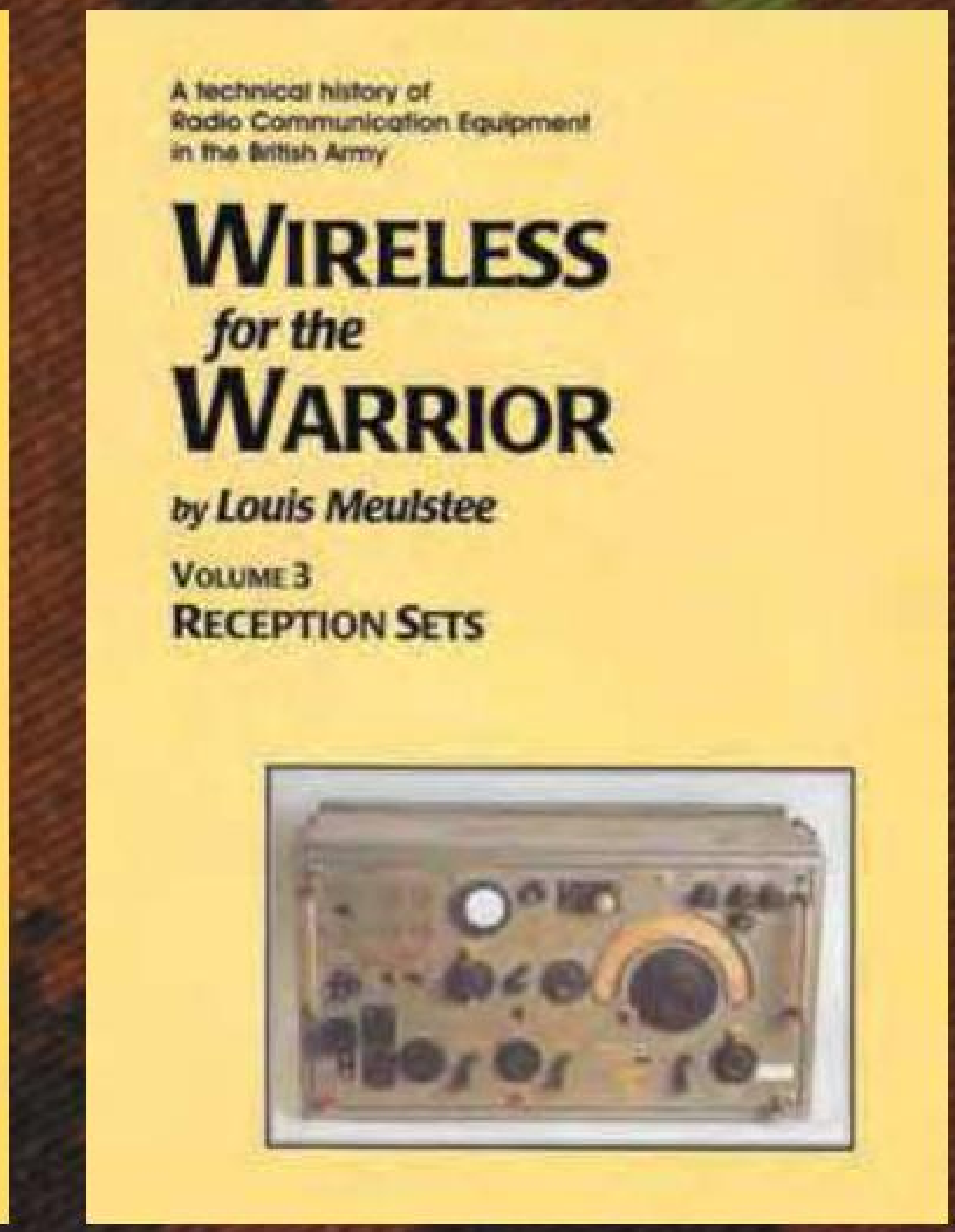
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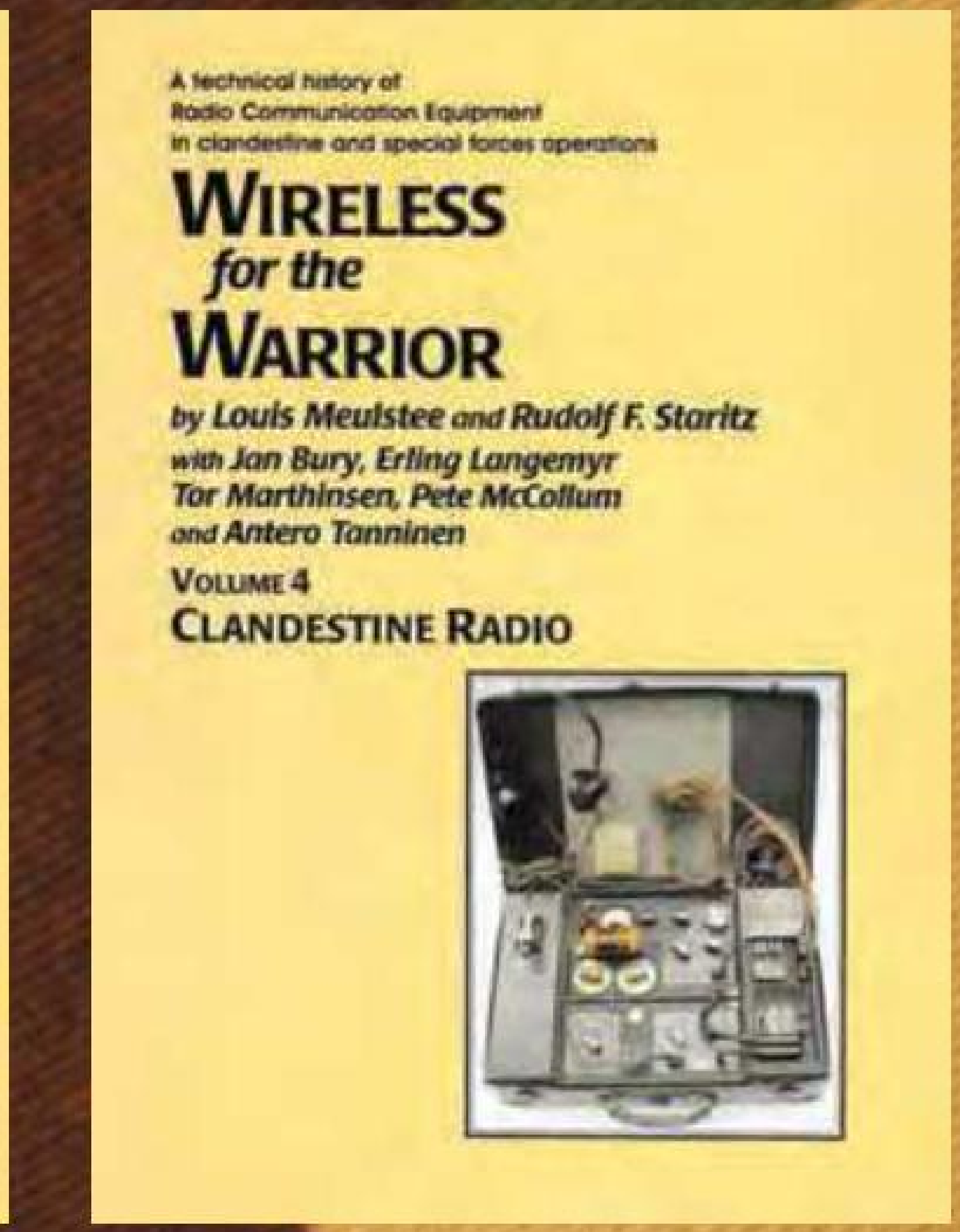
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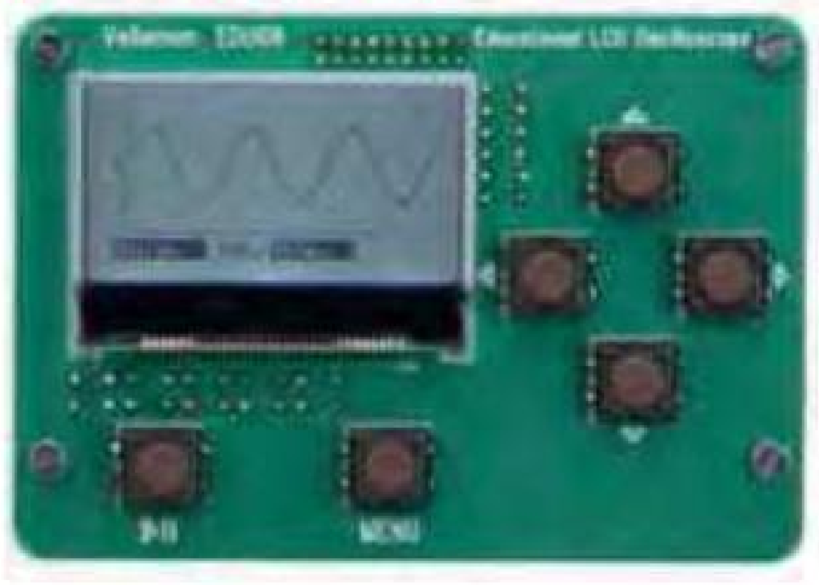

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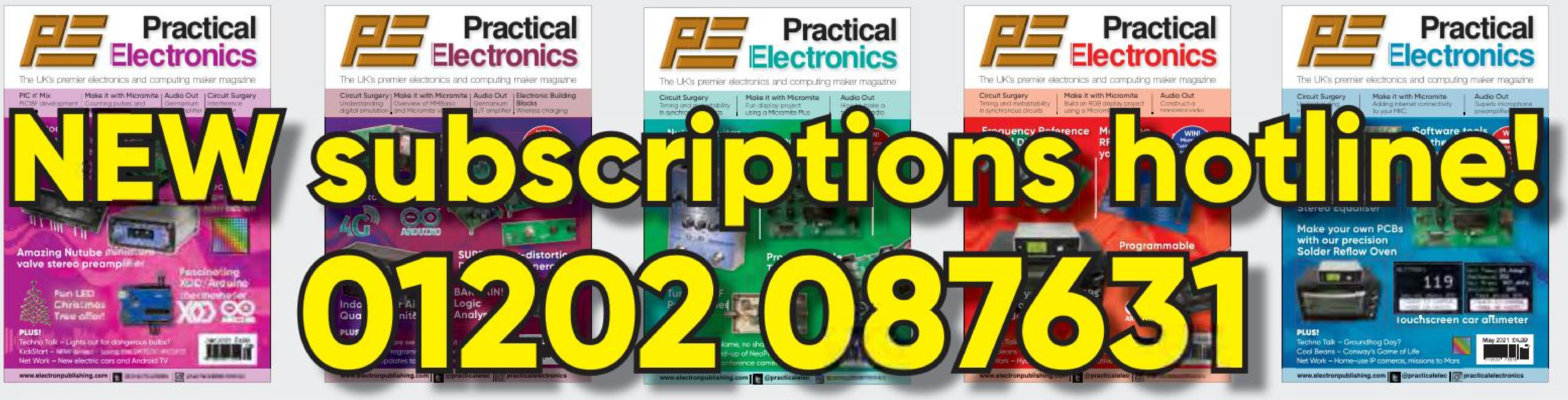

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Something for everyone

There's a pleasing variety of material in this month's issue of *Practical Electronics*. From fixing ancient amplifiers and a fascinating visual trip down Memory Lane to building and using the latest microcontroller technology. So let's dive into a more detailed look at this month's magazine.

tekkiepix.com

It's always a pleasure to read Barry Fox's eponymous column, and this month I asked him to write a little more about his new website devoted to saving and archiving important images related to the history of electronics, especially consumer products. For those of you unfamiliar with his work, Barry has been a leading UK electronics, IT and technology journalist for decades. Through his work he's created an important archive of images that need preserving and has launched a website to do just that. Please do pay a visit to **tekkiepix.com**, click on the Stories link and enjoy the material. If you are able to support his work and make a contribution, however small, then all the better.

Projects

Some audiophiles look down on graphic equalisers as an unnecessary, signal-damaging link in the Hi-Fi chain. I've always thought that was rather unfair; they do have their place and can be very useful in challenging acoustic environments. So, if you're in the market for a high-quality, low-cost design then this month we have just what you need. Even better, it comes in mono and stereo flavours, so why not give it a try?

Plus, we have the second and final part of our *DIY Reflow Oven* for those of you who make your own SMD PCBs and a fun *Digital Altimeter* especially suited to use in cars.

Digital fun

Where to start? Our authors really are excelling themselves this month. We have Max's wonderful ping-pong ball array playing Conway's *Game of Life*, Phil Boyce's must-read column on using the Micromite with the Internet and the latest from Mike Hibbett's exciting *PIC18F Development Board*. Truly, a feast for all fans of digital electronics and microcontrollers.

You want more? Well, naturally we have in-depth analysis from the word of electronics courtesy of Ian Bell's *Circuit Surgery*, and the start of a super high-quality *Microphone Preamplifier* from Jake Rothman in *Audio Out*.

Truly, something for all tastes!

Keep well everyone

Matt Pulzer
Publisher

The **Fox** Report

Barry Fox's technology column

tekkiepix.com

Why – you may well ask – have I spent most of my lockdown year building a website (**www.tekkiepix.com**) that has no obvious way of recouping what I have spent on it in time and hard cash? Why has another tech journalist, Richard Dean, who edited video magazines I worked with 20 or more years ago, put in his time and money too?

It's simply because we want to prevent a slice of consumer electronics history from being lost for ever. We couldn't go out from our bubbles, so we stayed in and worked on the website.

Today, tech companies promote products with publicity shots that are digitally shot, and digitally sent to the press and websites. The pictures are digitally stored and digitally indexed. Therefore, they are easily searched out, accessed and copied.

But up to around ten years ago, in the 'Days Before Digital', tech companies had to spend huge sums of money on using 'wet file' photography and sending out large quantities of professionally produced glossy paper prints and colour transparencies to the magazine and newspaper press, in the hope that a few might publish them.

Most of those 'physical' photos quickly ended up in waste bins. Some were filed away by magazines for future use, but many of those publications have since gone out of business, so their photo libraries have also ended up in waste bins. Many of the companies that sent out the photos have either disappeared or been taken over by venture capitalists. Their photo libraries were often junked or are gathering dust – but who knows where?

Experimental VERA (Vision Electronic Recording Apparatus) linear VTR developed by the BBC in the 1950s.

Many years ago, I decided to keep, rather than throw away, the most interesting and significant photos that postmen and couriers were delivering to my office. I was sure they would one day come in useful to me or someone else. Being busy with earning a living I just put them in loosely sorted box files and stashed them in my attic and garage.

A few years ago, I sorted through a few of the box files, laboriously scanned a few images, taught myself to build an amateur website, bought the domain name **www.tekkiepix.com**, paid for hosting and posted some of the pictures for anyone to look at. The Royal Television Society gave me a small grant, so I concentrated on posting pictures of TV and video tech. It was all very amateurish and stayed that way until Covid lockdown.

Iridium – a very expensive and not very successful satellite venture from Motorola to support analogue cell phones and pagers.

Bob Tomalski, a technical editor for *What Cell Phone?* magazine, managed to borrow an Iridium cell phone to try in Europe. 'Speech quality is appalling', he reported. 'It sounds like talking underwater through bubbles. At 2.4kilobits, it would take all day and cost a fortune to send a picture. It's Stone Age technology trapped in Space.'

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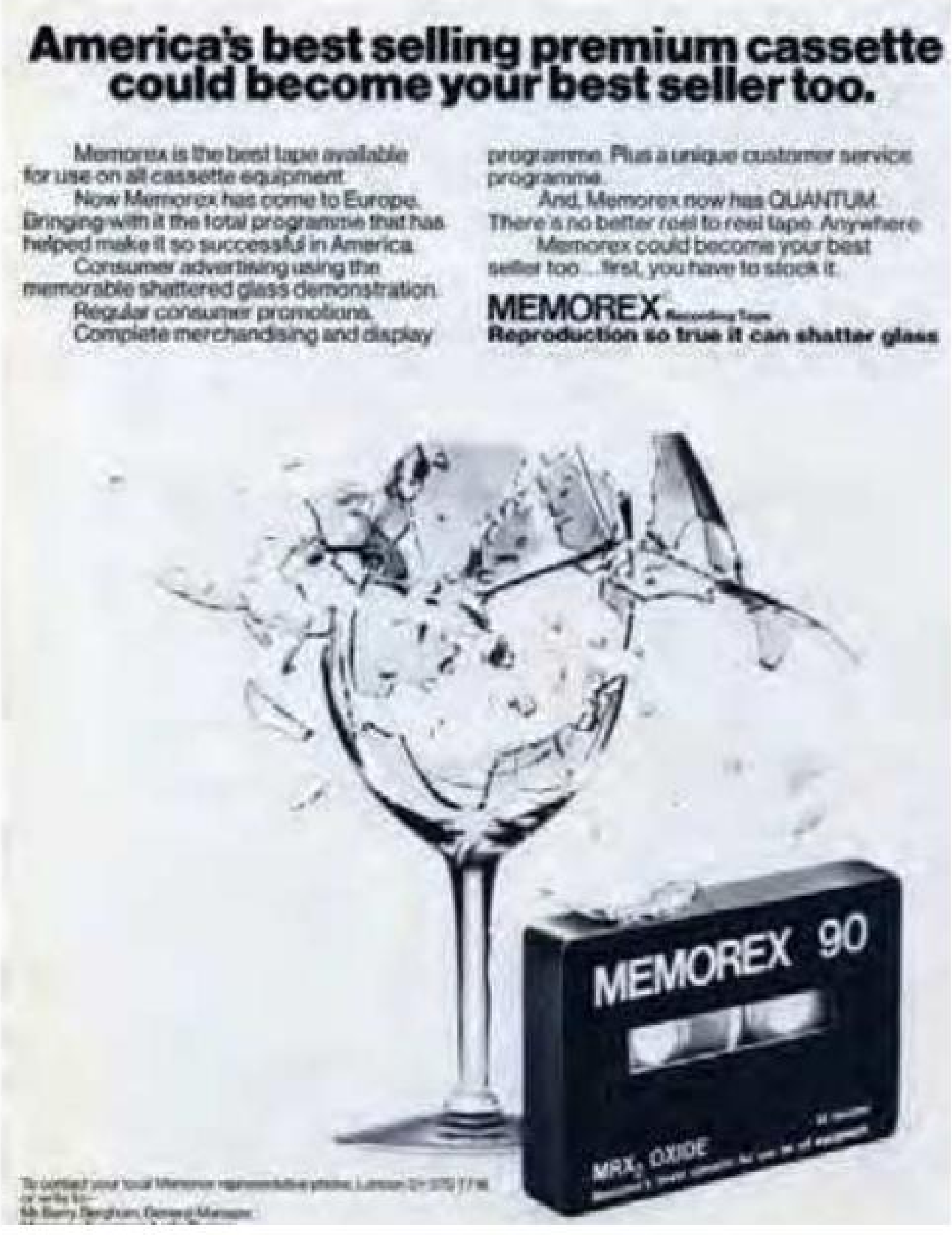


America's best selling premium cassette could become your best seller too.

Memorex is the best tape available for use on all cassette equipment.
Now Memorex has come to Europe. Bringing with it the total programme that has helped make it so successful in America.
Consumer advertising using the memorable shattered glass demonstration.
Regular consumer promotions.
Complete merchandising and display programme. Plus a unique customer service programme.
And, Memorex now has QUANTUM. There's no better reel to reel tape. Anywhere.
Memorex could become your best seller too ... first, you have to stock it.

MEMOREX Recording Tape
Reproduction so true it can shatter glass

In the early 1970s the market for blank cassette tapes was pretty cut-throat. US company Memorex was looking for a way to stand out, and hit on the idea of 'shattering glass'. TV adverts showed singer Ella Fitzgerald breaking a wine glass, as Caruso had supposedly done as a party trick.

The Memorex twist was that Ella recorded to a cassette that was then played back to shatter the glass – with the slogan 'Is it live, or is it Memorex?'

Hi-Fi buffs were up in arms. They did not question the fact that Ella's recorded voice could shatter a glass, if she hit a note that made the glass resonate, and playback was loud enough to make the resonance destructive. Memorex gave demonstrations to prove the trick worked, at public and trade exhibitions.

Witnesses were given certificates to prove that they had seen a glass break. But they had to wear ear protectors.

What Hi-Fi buffs did not like was any suggestion that it needed an especially good tape to do the job; it would have been hard to find a tape that did not fit the bill. A technical paper released by respected audio consultants Bolt, Beranek and Newman in 1973 revealed that the sound level used was well over 140 dB, which is way beyond the threshold of pain.

After prolonged debate, the UK's Advertising Standards Authority approved the adverts saying, 'although it is most unlikely that this effect could be related to the domestic situation, the Authority took the view that the advertiser was entitled to emphasise the qualities of his product by describing how it might operate in exceptional circumstances.'

Memorex – and Ella – had the last laugh though. The slogan stuck until Memorex was sold off and run down in the 1980s. And it broadened Ella's appeal at a time when rock music was ousting jazz.

With time forced on my hands I sorted and scanned some more images. After a chance online re-connection with Richard Dean, the tekkiepix site has now been revamped and relaunched in a far more professional form.

Have a look and see what you think. It costs nothing to access. There is a page for constructive comments; and a PayPal donation button for anyone who likes what they see and would also like it to continue and grow.

Whether this happens, with more pictures and the stories behind them added, now depends entirely on what donations roll in and whether any tech company, trade body, historic society or benefactor thinks the site and work worth funding.

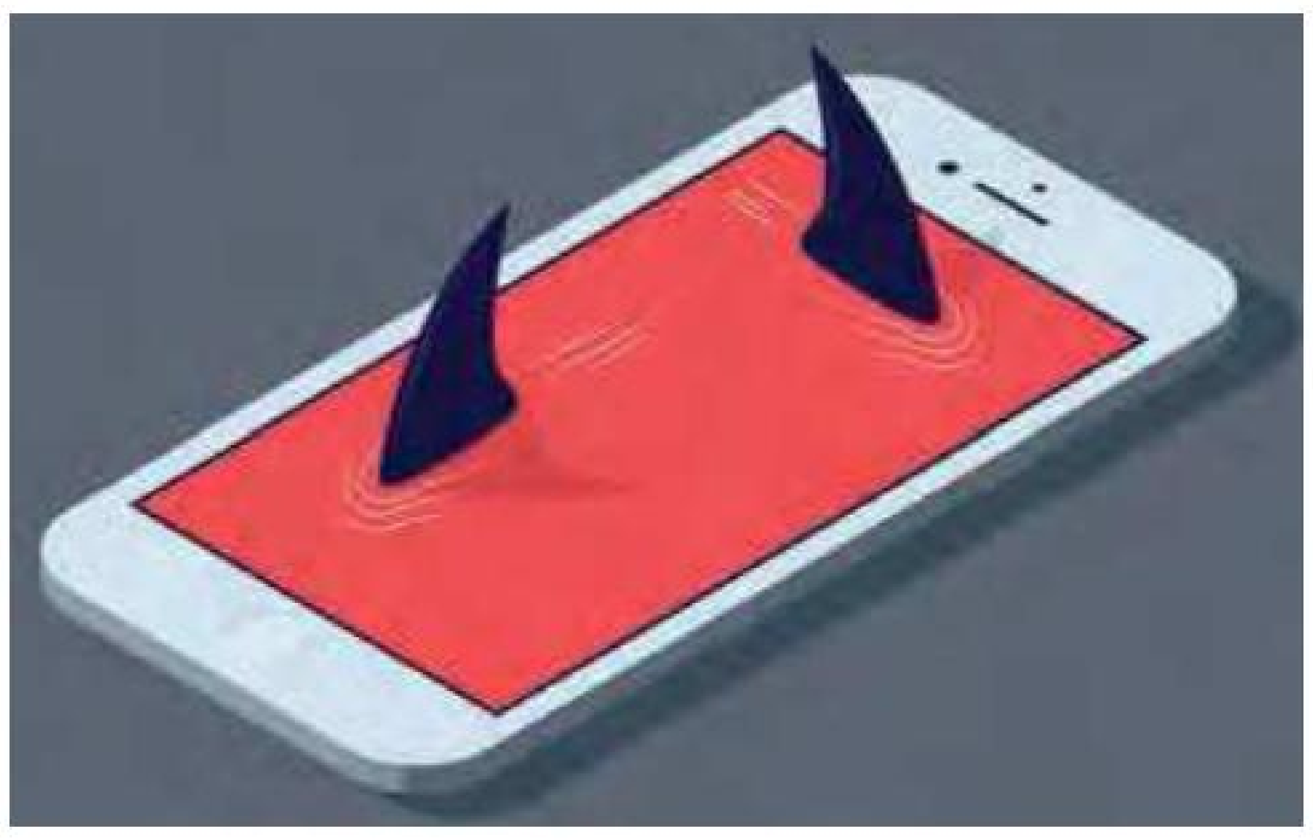
There are still many thousands of photo prints, large format transparencies and 35mm negatives and slides that I shot in factories and at exhibitions round the world, left to be digitised, indexed and posted on the site. For example, somewhere among the negs there will be some shots I took of a UK factory where most of the staff were smoking while assembling electronic equipment!

For the next year I'll pay what it takes to keep tekkiepix up and running, and maybe add some more content. After that all bets are off, because without support the site could shut down and the un-scanned images end up in landfill.

What reaction so far? Mainly positive and encouraging, albeit with one request from an ex-executive of failed satellite broadcaster BSB that I use what he reckons to be a more flattering mug shot of him. And no sign yet of any interest from any trade bodies or big companies.

Sinclair
microvision
2700

In the early 1980s Sinclair announced a £5m, four-year investment programme in a pocket FM radio/television receiver to be called Microvision. But the idea of a squashed tube was already doomed. At the Tokyo Electronics Show in 1980 Toshiba unveiled a pocket TV with a 2-inch monochrome LCD. The pictures were rotten, and smeared on motion, but it signposted the future.



Urban myth or scam?

Repeating web hearsay in capital letters, even underlining it in green ink, does not make it true, or alter technical basics.

As reported, it's become a factoid of the Internet that if we answer an incoming phone call from an IVR (Interactive Voice Response) call centre and do as the recorded voice says and 'Press 1 to speak to an adviser', a scammer can somehow, magically, connect us to a premium line costing several pounds per minute.

When I asked purveyors of this unsubstantiated scare story for hard evidence of how even the cleverest scammer can play the technically impossible trick of converting an incoming call into an outgoing call at the press of a single button, I was pointed to other Internet postings, such as an article in a Northern newspaper that quotes an anonymous policeman who apparently knows zilch about telecoms technology: **http://bit.ly/pe-may21-myth**

So, for the benefit of anyone who is interested in hard facts rather than cyber pub gossip, I spoke to Ofcom, the body which controls all telecoms in the UK. If such misuse of our phone system were possible, Ofcom's duty would be to stop it.

And Ofcom confirms: 'We have not seen any evidence to suggest that pressing 1 or any other digit can turn these kinds of calls into premium rate calls… pressing a digit is part of an IVR and the call is transferred to an actual person. It could be that in the script the consumer is being told to call back to a premium rate number – which could be where the call charges then happen.'

Of course, for most people it will be simplest just to hang up when a scam call centre says, 'Press 1'. And always remember the golden rule – never, ever give out genuine personal details to any cold caller, or phone any number the cold caller volunteers. But for those who feel confident in having some fun by wasting scammers' time and so eating into their opportunity to scam others more vulnerable, we now have it confirmed by Ofcom: simply pressing 1 during an incoming call cannot initiate an outgoing call to a premium line.

Groundhog Day?

Techno Talk

Mark Nelson

Déjà vu? That feeling you've already experienced something that is actually happening for the first time. Two of this month's topics may look familiar, but they are actually follow-ons, not repetition, and the rest is entirely new. It's easy to work out which is which!

Back in the early 1970s, there was a trendy shop in London's Tottenham Court Road going by the exciting name of 'Cassette Revolution'. Plenty of record shops were selling albums as pre-recorded 'musicassettes', but the shop named above was brave enough to sell no vinyl at all, which was pretty revolutionary at the time. Subsequently, CDs virtually killed off compact cassettes, with CDs in turn giving way to downloads and streaming for many folk. Two disruptive trends then followed: the vinyl revival and the cassette comeback. Generation Z has rediscovered tape, although bizarrely, some buyers don't even own tape players. Instead, they use the tape as a form of memorabilia!

Data tape is back too

Even more surprising, tape is making a comeback among professional users too. A report in *The Economist* last December made the remarkable statement that despite its archaic image, magnetic tape has a surprisingly promising future in data storage. The simple truth is, hard drives are costlier than tape, have shorter lifespans and the amount of heat that they generate makes hard disc storage undesirable for universal use. So-called 'cold' storage of data that requires only occasional access can be handled more economically on tape. Even better, the report continues, the storage density of magnetic tape has been increasing steadily, by 34% a year for nearly three decades, meaning that tape may catch up with hard drives within five years.

All this makes perfect sense, if you have mission-critical data that requires unconditionally reliable, long-term storage and you have the space and climate-controlled premises. No other data storage medium that I'm aware of can beat tape in that scenario. Flash drives and other solid-state media are for short-term storage only. And as victims know, hard drives are vulnerable to head crashes and DVD-Rs can lose their data in five years or less (I have learnt bitter lessons in both respects).

Unfortunately, the vulnerability of unwise data storage does not get through to consumers or companies which are not tech-savvy. When I worked at a well-known car manufacturer's HQ in the late 1970s, they lost a whole month's worth of accounts data when their preferred data storage medium failed. The accounts staff had to recompile everything from scratch (and benefitted from unlimited overtime for the next four weeks!). And what was that preferred data storage medium? Compact cassettes! No, not the sort used in your Walkman but the data-storage type that had a large identification notch in the cassette housing. These tapes were not optimised for audio use; but they did, nevertheless, fit in a normal cassette machine's tape deck, which is why some office thief nicked them.

Openreach still on the learning curve!

Way back last December, we chastised BT Openreach when it took 18 months to sort out poor broadband connectivity and slow speeds in north Wales. It blamed these issues on an unsuppressed old television receiver instead of inadequate filtering and screening of its network hardware. Any lessons learnt in Wales appear not to have filtered down to other parts of this Sceptred Isle, as this report from our West Country correspondent proves.

He writes: 'I previously mentioned a colleague and his neighbours who are blighted by an RFI/EMI fault that crashes their broadband regularly. Sounds like a mains PME fault to me. Had it myself when I worked for BT Openreach, but they have not handled this properly or effectively. Why? BT sent him a new hub, as if a new hub would solve the problem!' PME is 'protective multiple earthing', and if a fault occurs on the combined protective earth and neutral conductor, then the neutral conductor of your mains wiring may not be properly earthed. There's a technical discussion on these problems at: **http://bit.ly/pe-may21-tt**

The 'colleague' bought a mains EMI filter and says it has reduced the frequency of crashes and the broadband now recovers more quickly after a crash. On the other hand, his neighbour has fallen out with his service provider entirely because of the unresolved fault. Instead, he ditched the landline altogether and is now using 4G cellular for both voice and broadband.

Mucky mains again

The March edition of this column recalled the problems that plagued Gerry Wells of the Vintage Wireless Museum in London, which he had put down to what he called 'dirty electricity'. He died in 2014 and never accessed the Internet and Amazon's emporium. Had he lived another seven years, he could have bought an AlphaLabs Dirty Electricity Meter, a natty-looking power line monitor that displays noise on a colour screen, calibrated in mV peak-to-peak. Even better, a built-in loudspeaker plays the alleged sound of the electromagnetic interference, amplitude demodulated, in order to identify the EMI source (such as an AM or shortwave radio station vs. a motor vs. an electric arc).

Only Gerry wouldn't have bought it at the £161.99 price asked, because he didn't spend money like water. That said, the gadget is quite neatly turned out (see **https://amzn.to/3cWr4LZ**). On its own, the meter/detector is exactly that and only indicates how 'dirty' your mains supply is. To resolve the problem, you need to buy also the DE2 Dirty Electricity Mains Filter, costing £45.60. This will filter out the EMI interference and 'reduce' the dirty electricity in your house. Probably.

More free electricity!

Researchers at the University of Colorado have demonstrated eco-friendly thermoelectric generators that convert your body heat into elelctricity that will power body-worn devices. The 12.5µW delivered at 5V can drive most low-power sensor nodes with radio-frequency communication. Internal wiring of the devices uses liquid metal, resulting in self-healing properties, Lego-like reconfiguration and good recyclability. Best of all, the devices cost $10 to make. More details at **doi.org/fvdv**

Win a Microchip ATtiny3217 Xplained Pro Evaluation Kit

Practical Electronics is offering its readers the chance to win an ATtiny3217 Xplained Pro Evaluation Kit (ATTINY3217-XPRO) – and even if you don't win, receive a 20%-off voucher, plus free shipping for one of these products.

The ATtiny3217 Xplained Pro evaluation kit is a hardware platform for evaluating the latest tinyAVR microcontrollers. Supported by the Atmel Studio and MPLAB X integrated development platform, the kit provides easy access to the features of the ATtiny3217 and explains how to integrate the device into a custom design.

The ATtiny3217 Xplained Pro is recommended for evaluation of the following products: ATtiny3217, ATtiny3216, ATtiny1617, ATtiny1616, ATtiny1614, ATtiny1607, ATtiny1606 and ATtiny1604.

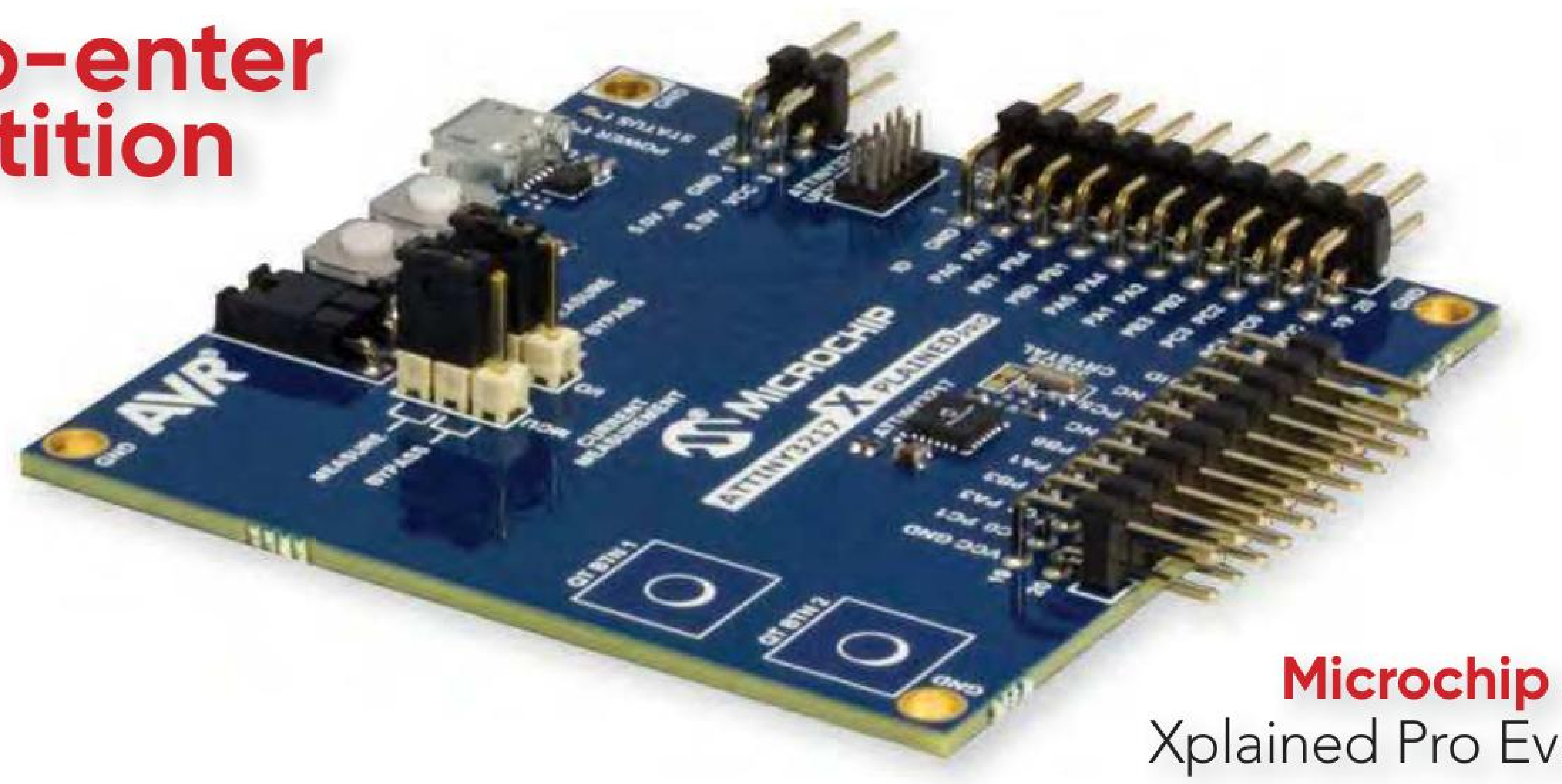
The ATtiny3217 series of microcontrollers features the 8-bit AVR processor with hardware multiplier, running at up to 20MHz and with up to 32KB Flash, 2KB SRAM and 256B of EEPROM in a 24-pin package. The series uses the latest Core Independent Peripherals with low-power features. It also includes an Event System, intelligent analogue and advanced peripherals. Capacitive touch interfaces with proximity sensing and driven shield are supported by the integrated QTouch Peripheral Touch Controller (PTC).

This series of microcontrollers is recommended for safety-critical applications (www.microchip.com/design-centers/8-bit/functional-safety), targeting industrial and automotive products (IEC 61508 and ISO 26262).

The ATtiny3217 Xplained Pro currently supports more than 20 extension boards – including wired and wireless connectivity, crypto authentication, QTouch capacitive touch kits as well as generic I/O and OLED boards. Extension boards are not included with the ATtiny3217 Xplained Pro evaluation kit, but can be purchased individually.

Worth $38.00 (approx £27.50) each

Free-to-enter competition



Microchip ATtiny3217 Xplained Pro Evaluation Kit

How to enter

For your chance to win an ATtiny3217 Xplained Pro Evaluation Kit or receive a 20%-off voucher, including free shipping, enter your details in the online entry form at:

https://page.microchip.com/PE-ATtiny.html

Closing date

The closing date for this offer is 30 April 2021.

January 2021 winner

Mathias Heier

He won a Microchip SAM IoT WG Development Board

Net Work

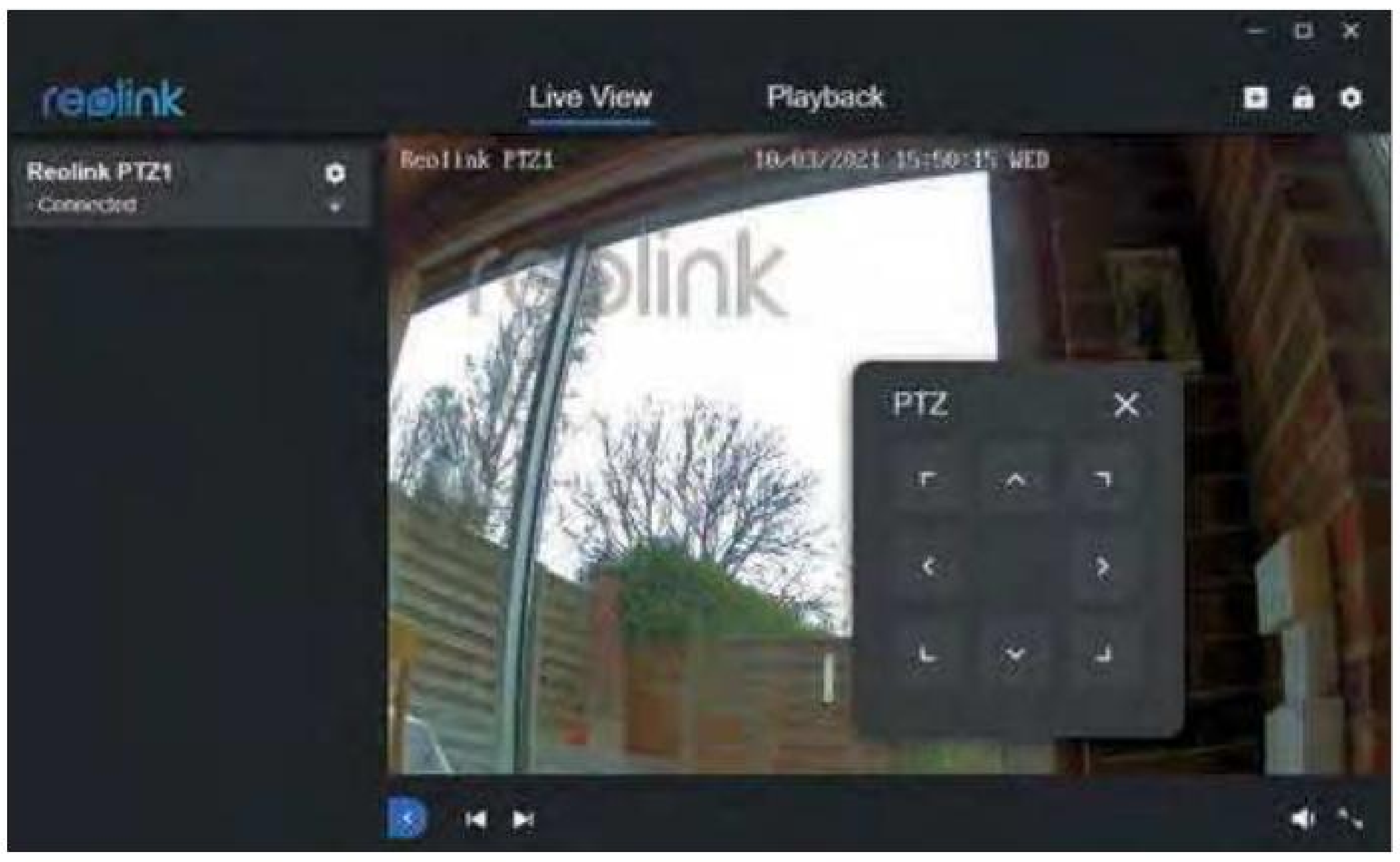
Alan Winstanley

This month, *Net Work* revisits home-use IP cameras, marvels at the current missions to Mars from NASA (and others) and reveals the latest money spinner from eBay – for eBay, not you.

The topic of IP security cameras has cropped up in *Net Work* for over a decade, as demand for surveillance systems rose, and slow, stuttery and often unreliable home devices gradually became available. Today, any home user keen to add a feature-packed camera onto their home network is spoiled for choice. Whether they deliver on their promises is often the subject of trial and error though.

I previously outlined some key features that prospective buyers of IP cameras might bear in mind. For use indoors, wireless (ie, Wi-Fi) cameras promise simplicity of installation, but good Wi-Fi coverage is almost mandatory although some cameras also have wired Ethernet ports. If the Wi-Fi network is patchy, powerline communication devices (PLC) such as Devolo or TP-Link PLC products carry IP traffic through the electrical rings mains and are a good option. An onboard microSD slot offers local storage of snapshots or video clips, which will be fine unless the camera is stolen. Some camera brands (supposedly) sell cloud storage that hosts video footage off-site (see later). A mobile app usually allows a camera to be set up and its video feed monitored. Some cameras provide shared access over the web, or via a paid-for cloud network, or by using a mobile app login. Monochrome night vision with IR illuminator LEDs is common, which often needs disabling if a camera is behind a windowpane. A microphone and speaker may offer two-way voice comms of sorts. A power source within easy reach is needed, often a 5V USB-type.

The Reolink E1 Pro is a low-cost pan-tilt network camera that is performing well – so far.



A Windows 10 app is available for desktop control of Reolink cameras. Note the pan-tilt controls.

PTZ options

Most cameras are static, but some offer motor-controlled coverage of the target area. In December 2020's *Net Work* I looked at the HeimVision HM311, a decently made, fixed outdoor camera with some small built-in security lights that generally worked very well. Spurred on by the encouraging performance, in the March 2021 issue I tried their HM202A PTZ (pan-tilt-zoom) indoor IP camera, a budget network motorised camera that trades at about £35 or so, and is typical of this level of security gadget. Several months later and regrettably, readers, this Wi-Fi/ Ethernet camera bit the dust: it started disconnecting and crashing constantly, usually when playing back video clips over the network. The camera's motion controls became nearly unusable and frequently it ended up staring at a brick wall unresponsively. A mobile app upgrade made it fiddlier to control and the app seemed to push paid-for cloud storage. It was returned fuss-free under warranty.

Reolink pan-tilt

Next up was a duo of Reolink 'E1 Pro' pan-tilt indoor home cameras, which cost about £75 a pair after discounts. The Reolink brand has been highlighted before as a popular and well-regarded brand, and these cameras are typical 'swivelling eyeball' types for residential use (note that this product works on Wi-Fi only). On the upside, they are dual-band 2.4GHz and 5GHz devices which should help make them futureproof.

It has up to 4MP (2560 × 1440 px) resolution along with two-way audio. A microSD slot is hidden from view to help deter tampering (so much so, that some buyers even ask where it is!). They have a typical lightweight plastic construction, as they only have small DC motors to control them. It's likely that a 'patrol' mode, sweeping the lens from side to side, would simply wear them out, which is why patrolling is not an option at this sort of price level.

The supplied 5V 1A mains adaptor has a hard-wired 3m lead terminated with a 2.5mm barrel plug. If you want to cook your own power supply, I found 2.5 × 0.7mm extension leads as well as USB A-type leads were sold on eBay. With home users in mind, the camera is freestanding and a simple plastic bayonet bracket, with drilling template, allows for ceiling mounting. It has no tripod screw.

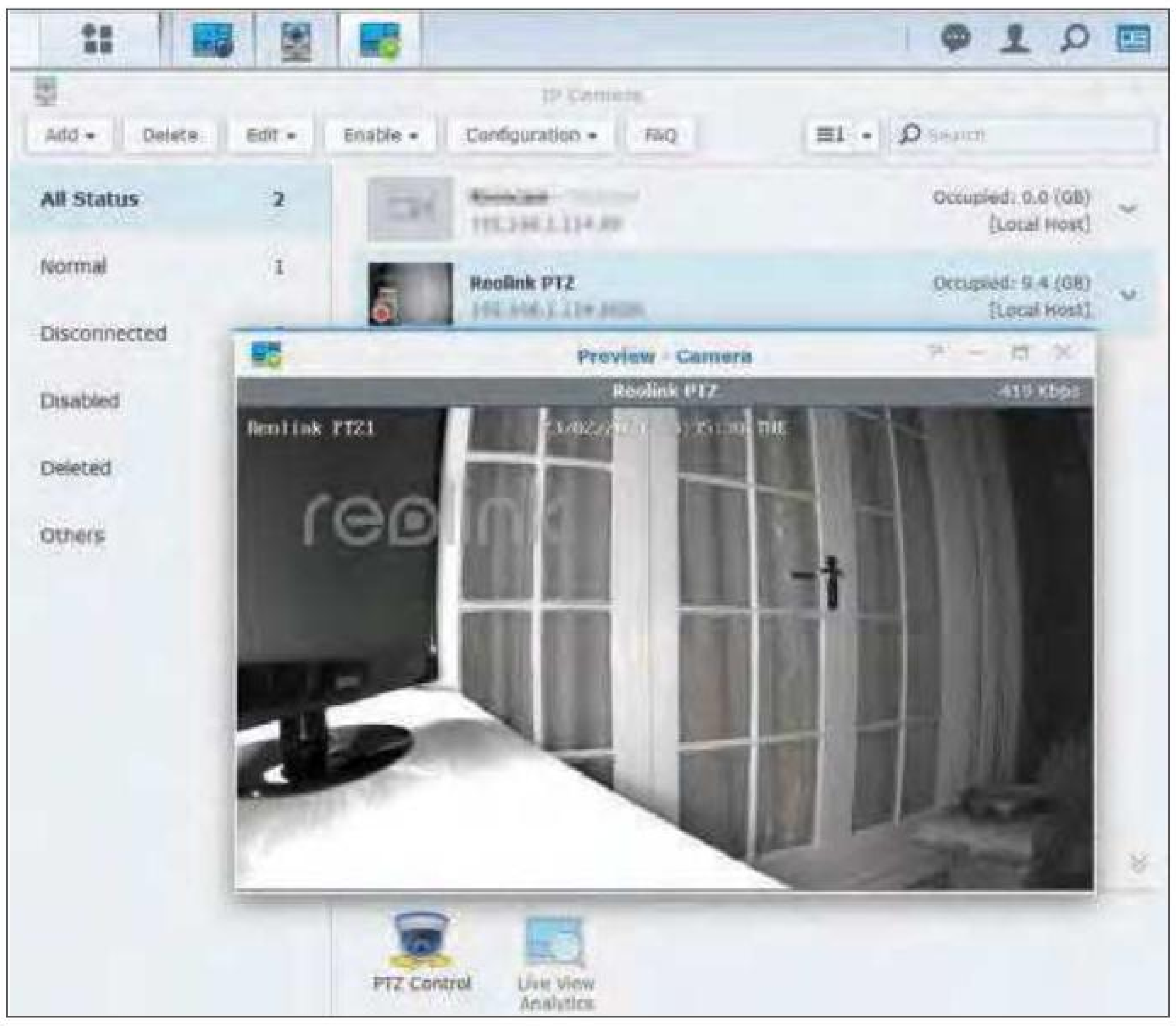
While the HeimVision camera had a decent little user manual, the Reolink is only furnished with a *Quick-Start guide* and the bulk of user guidance is published online. Being Wi-Fi only, installation was performed by installing Reolink's mobile app and adding a device. The camera lens scans the displayed QR code, a password is input, and setup was completed in a very slick process. The mobile app then offers a live video stream, and over the Wi-Fi network the motor controls were responsive and smooth with barely any overshoot or lag. I found it performed much better than the HeimVision in an identical setting. Arrow icons appear onscreen showing the lens's direction of travel when moving. The 'Reolink' image watermark can be disabled, and a moderate siren sound in the camera can be activated by either detecting motion or manually, if you want to put the frighteners on an intruder (or your granny!).

The Reolink app triggers an alert when motion is detected and, once SMTP details are entered, it can email a text or attach snapshots or video clips. The camera depends on an optional microSD card to stream as a network video recorder (NVR). The spec claims 64GB maximum, but I tried a fast 128GB card without noticing any problems. It replays at between 0.25× to 16× actual speed, with pre-trigger and post-trigger recording adding some context. Snapshots and video clips can also be taken manually or downloaded onto the phone, and the app's simple editor does a neat job of 'scrubbing' and clipping the video when saving. As mentioned, there is no simple web-based access, but the camera feed can be shared with friends and family using the app on their own devices, if they snap another QR code.

Get off my cloud

At this point I considered the option of cloud-storage. Cost generally depends on how long data is stored before being overwritten (eg, 7 or 30 days), and whether recordings are taken 24×7 or are triggered by motion only. HeimVision's cheapest package, for example, costs approximately $6 per month *per camera* (**http://bit.ly/pe-may21-heim**) or up to $134.99 per year, but when checked online all cloud storage plans for the HM202A PTZ (reviewed in March 2021) were 'out of stock'! At the time of writing, Reolink's Cloud storage is hosted on Amazon AWS but was not available for sale in Europe due to the current lack of GDPR compliance, they say. (But the UK isn't in the EU, and whether any breach of data privacy regulations could be enforced in China is a moot point anyway.) Hopefully, cloud storage will roll out in due course. Some other Reolink cameras offer FTP uploading, for those who run their own servers.

Reolink also provides a dedicated Windows app, which installed in W10 without a hitch. It provides on-screen pan/tilt control and playback, as well as allowing users to take snapshots and video clips to save onto, for example, a NAS storage drive. You can zoom in on the image digitally. Recording schedules can be set up in the app as well, as can privacy masks and motion detection zones. Compared with some bundled packages that are rough around the edges, I found Reolink's Windows app to be a modern and well-designed app offering good desktop control of lens positioning. A second Reolink camera was then added, giving a multichannel view (four, maximum) on the mobile app and the Windows desktop PC.



Synology's Surveillance Station installs on a NAS and is a very powerful monitoring and recording system for network cameras, including the Reolink E1 Pro tested here.

When tested out and about, viewing the live streaming video and playback over mobile data was very satisfactory. The author found the pan-tilt motion control very usable with little lag (recall that video and snapshot recordings can be taken manually on the mobile phone). It claims to be compatible with Google Assistant, but this has not been tested yet. Overall, the Reolink E1 Pro seems to be a very well-sorted pan-tilt camera for home use with very few vices; plus, Reolink's website has a wealth of support material. That said, I would have liked to have seen an Ethernet port and a standard USB-type power feed rather than a dedicated mains adaptor. The E1 Pro is available from Amazon or direct from: **http://bit.ly/pe-may21-e1**

Under Surveillance

Reolink has another trick up this camera's sleeve: it is Onvif-compatible, so in theory it could run on a home or office camera package such as Synology's sophisticated Surveillance Station. Owners of Synology NAS drives can create a comprehensive multi-channel network video recorder and Onvif camera controller using this software package. It has every feature imaginable to satisfy even the most paranoid of users, and possibilities include joystick controllers (untested) and deep video analytics, leading to people counting, facial recognition and more. Each Synology package includes a licence for two cameras, and more camera licences can be bought separately.

Having a basic Synology NAS on my own home network, I decided to try this idea out. Installing Surveillance Station took a single mouse-click followed by a very lengthy delay to download and install it. My basic NAS installed the Reolink E1 Pro successfully, which proved a point, but in reality, my own Synology NAS just wasn't up to the job. Surveillance Station needs a powerful NAS and fast network, and the software is probably an area reserved for power users. More details of Surveillance Station are online at: **http://bit.ly/pe-may21-syn**

Bare Synology or QNAP NAS systems are available from major IT vendors; sold separately are hard disks optimised for being thrashed by surveillance recording and streaming tasks, notably the Seagate SkyHawk and Western Digital 'Purple' ranges. Windows 10 also makes it easy to use dual monitors to get more screen 'real estate' if you're stuck for space watching everything, see January 2021 *Net Work* for some tips.

There is plenty of choice available for those wanting to try an IP camera on their home network, and hopefully the Reolink will fit the bill for a budget-priced device that's easy to set up and control. Note that all cameras mentioned here have been paid for by the author – no freebies – and I'll doubtless give readers a progress report in coming months.

Mars attacks!

As *Net Work* readers doubtless know, NASA's latest leg of its Mars Exploration Program was completed in mid-February with a spectacular touchdown of the sophisticated Perseverance rover followed by the vehicle's first tentative test drive in early March. What readers, especially overseas, might not know is that Perseverance is actually being controlled, in part anyway, by a NASA scientist working from a one-bedroom flat in London. Professor Sanjeev Gupta should be in

California, but found himself stranded in the UK during the Covid lockdown, so an apartment above a hairdressing salon has been pressed into service with a couple of laptops acting as a makeshift nerve centre.

Attached to the rover is a small helicopter drone called *Ingenuity*, which has 'checked in' successfully and its solar cells are charging it up, ready for some proof-of-concept test flights. If successful, it would be the first such flight on an alien world. Up above, China's own Mars orbiter, Tianwen-1 ('Questions to Heaven') is circling the planet and its own lander/rover is expected to be released to land on the surface mid-year.

The United Arab Emirates Space Agency also celebrated the arrival of its 'Hope Probe', the first interplanetary mission conducted by an Arab nation. The UAE Hope orbiter was launched from Japan last July and is currently circling Mars, tasked with analysing its atmosphere. Space fans can enjoy their drag-and-drop tracker in the solar system at: **http://bit.ly/pe-may21-mars**

A further 240 Starlink satellites were slated for launch in March by SpaceX using its re-usable rockets, as it continues to build its network of laser-connected, LEO (low-earth orbit) satellites, designed to beam satellite-based broadband down to Earth. More than 1,200 satellites have been launched, and its Starlink service is starting to roll out for early adopters (apply at: **www.starlink.com**). SpaceX also has in its sights on the provision of Internet access for moving vehicles.

OneWeb, the satellite operator brought out of bankruptcy by the British Government and India's Bharti Global, is said to be in talks with British Telecom to provide satellite-based services to hard-to-reach areas in the UK. Initially floated as a possible option for a post-Brexit UK GPS network, that idea was silently shelved leaving the UK Government under pressure to justify the cost of the bailout in the first place.

And finally…

In other news, in an effort to build 'trust' into online content, major IT and media companies have formed the Coalition for Content Provenance and Authenticity (C2PA). It intends to fight disinformation, misinformation, fake news and fraudulent content by providing traceability of content back to its origins, and is the brainchild of Microsoft, Adobe, Intel, the BBC and others.

RE- No Tills? Just Walk out!!
Lane closed
TO MAINTAIN SOCIAL DISTANCING

Inside the UK's first Amazon Fresh store in London (Credit: YouTube / Hannah Ricketts)

The board of Nominet, the UK body that oversees the **.uk** ccTLD (country-code top level domain) space, has been toppled after a number of discontented members mobilised to demand major re-forms to the organisation's governance and a return to more altruistic values. After failing to fend off an extraordinary general meeting called by a group of smaller players, Nominet's CEO Russell Haworth resigned and four directors were voted out in March. The website **PublicBenefit.uk** cited Nominet's 2/3 drop in public benefit donations, coupled with massive directors' pay rises and a 38% fall in profits as reasons for their dissatisfaction. Some members also cited their lack of trust, after Nominet pulled the plug on their official forum to silence them, which fuelled more anger against Nominet's management.

…wind energy news

GE Renewable Energy in partnership with asset manager firm Luxcara is building Europe's largest onshore wind farm at Önusberget in northern Sweden. Using GE's new 'Cypress' wind turbine platform, up to 137 of the 5.5MW turbines will deliver 750MW of power, equivalent to the generating capacity of a nuclear reactor. The 158m-long turbine blades incorporate an ice-mitigation system, GE says, to deal with the Swedish climate.

Regular *Net Work* readers might recall my coverage of GE's Haliade-X offshore wind turbine, which is at the heart of Hornsea One, currently the world's largest offshore wind farm off the coast of Yorkshire, England (see *Net Work*, January 2020). These 14MW monoliths might soon face Danish competition thanks to Vestas Wind Systems' prototype 15MW turbine. As the market for wind turbines hots up, makers aim to reduce operating and electricity production costs by having fewer but longer turbine blades that generate more power. A very interesting and highly readable blog by wind energy engineer Sarah Barber explains a wind turbine's AEP (Annual Energy Production), its rated power and more besides at: **http://bit.ly/pe-may21-wind**

What to do with wind turbines that reach their end of life? These machines may last 20-25 years, depending on environmental factors. While up to 95% of the machinery can be recycled, the enormous turbine blades themselves can weigh up to 50 tons each and are made of complex composite materials that end up in land fill. Studies are now under way to recycle them, including the Danish-funded DecomBlades project which hopes to research ways of shredding turbine blades to produce a consistent raw material that could be used in Portland cement, for example. Some interesting background is at the blade manufacturer LM Power's site at: **https://tinyurl.com/yd5dzt9t**

…Amazon shopping in London

Amazon has launched its first walk-in/walk-out retail store outside of the US. Based in Ealing, London, visitors to the Amazon Fresh store identify themselves by scanning a QR code on entry before shopping in the till-free store. Amazon uses its 'Just Walk Out Technology' combining AI techniques and cameras to follow shoppers around the store. When done, shoppers just walk out, and Amazon bills them

An image from the first journey of NASA's Perseverance rover on 4 March 2021. One of its Hazard Avoidance Cameras captured this image when manoeuvring at its landing site in Jezero Crater. (Image: NASA/JPL-Caltech)

'automagically'. One shopper likened it to 'feeling like you've left without paying'. A second store opened soon afterwards at Wembley. There's a YouTube walkaround at: **https://youtu.be/2yoJ-LV3iTU**

...eBay and PayPal

Dressed up as an 'improvement', eBay UK has updated its PayPal selling terms after divorcing from the ubiquitous payment processor. The online marketplace has inserted itself into the payment chain, and says 'eBay now manages the end-to-end selling experience on our marketplace, including payments.' Buyers using PayPal will find themselves paying eBay (eg **Paymentsinfouk@ebay.co.uk**) rather than funding the seller's own PayPal account. Sellers now face delays of up to two business days before eBay pays them directly into their bank account; on the plus side, Paypal fees charged to sellers will be eliminated. eBay will also deduct its fees immediately, rather than billing sellers in arrears by direct debit, a move that advances eBay's own cash flow while retarding that of their sellers. Previously, if I sold anything on eBay I could use the PayPal revenue to pay a courier directly from the proceeds, but not anymore. The real winners in all this are eBay.

Details of the new terms are on **http://bit.ly/pe-may21-ebay** and it's worth remembering that under UK law, consumers using PayPal are purchasing directly from PayPal, not from eBay or the vendor, so they still don't enjoy the same consumer rights as someone buying 'direct' using a credit card.

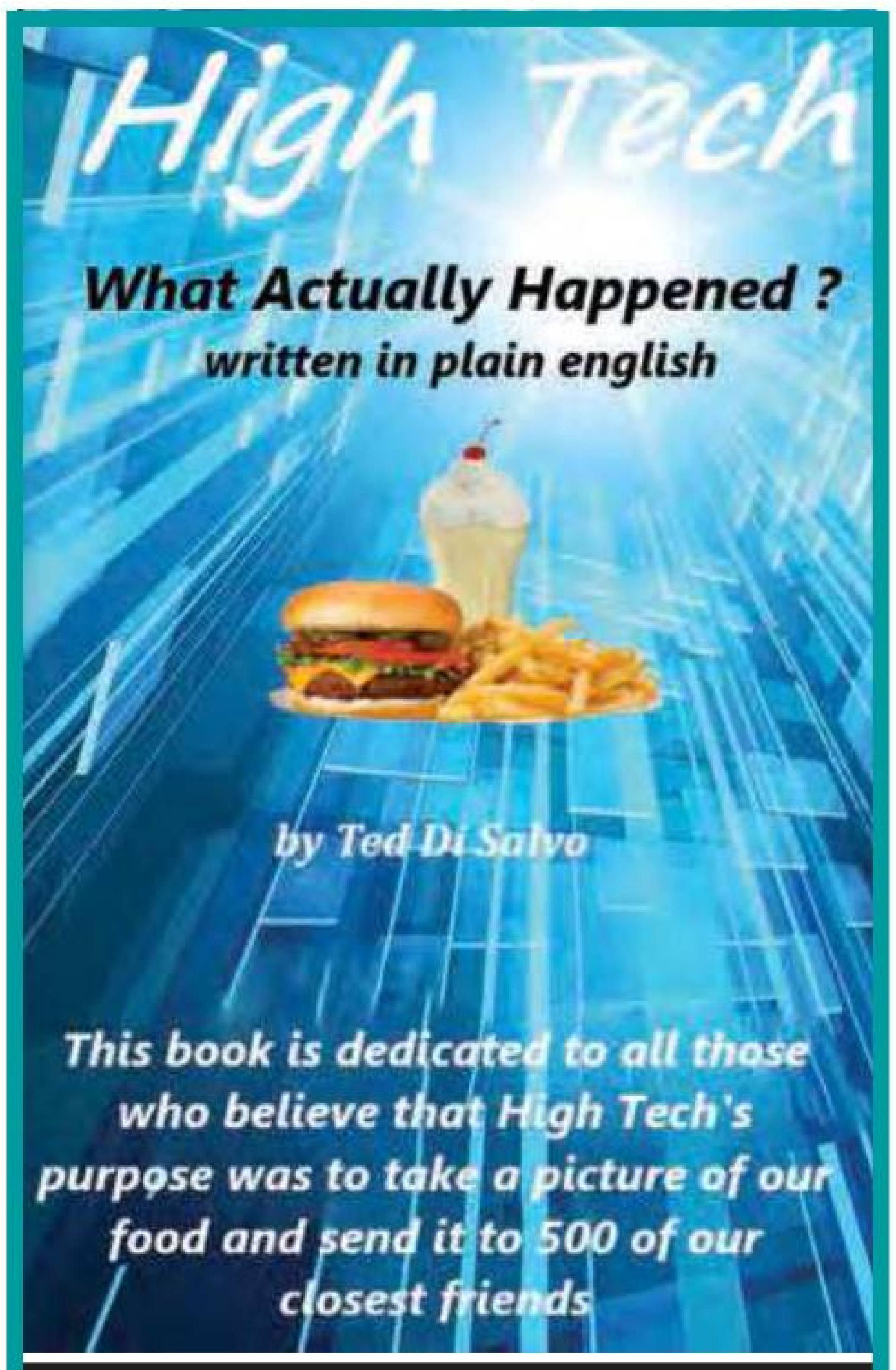
A corrected caption!

Last, this month, my thanks go to regular reader Stephen Alsop who wrote in following last month's *Net Work*: 'Another good article in this month's *PE*. I liked the mention of the late John Becker. He was my hero in that I had started to use PICs in my industrial projects and jobs from the early 90s, all done in assembler obviously (some can be seen in my simple one-liner project list on my website, **alsop.co.uk**). I think the first I used was a PIC1650/52 or suchlike, where erasing was done in a UV box.

'John created the best-ever articles using PICs – the altimeter, the compass and wind direction device using ultrasonic sensors… what a clever man. He explained them fully and clearly, and together with the explanation of the source code made each project the ultimate model of how to teach within a construction article. I am forever indebted to him, as he brought me on in leaps and bounds. More knowledge has flowed through *PE* than many places of higher education.

'However, my reason for writing was to point out that the picture of John Becker with Sir Clive Sinclair on page 13 [April issue] says it was taken at the 25th anniversary birthday of *PE* in 1992. I still have my first *PE* magazine and it is November 1964 and so the 25th should have been 1989.

All the best and please keep the articles informative and enlightening.'


High Tech
What Actually Happened ?
written in plain english
by Ted Di Salvo
This book is dedicated to all those who believe that High Tech's purpose was to take a picture of our food and send it to 500 of our closest friends

70 years of technological developments have brought us to today. Some of these advances were monumental and game changing in their own right. Some significant spin offs have revolutionised many unrelated areas. The author has had a front-row seat through most of this revolution and puts it in perspective in plain English.

Available on Kindle or in paperback at Amazon

Thank you for writing, Stephen. You're right to point out the error in my caption on page 13 last month. John's interview with Sir Clive Sinclair appeared in the 25th year issue of *Practical Electronics* which was the November 1989 edition, as you rightly say. The photo I used last month actually came from the October 1992 issue and was (I think) previously unpublished – another milestone magazine, as it was the very last *PE* under the old stewardship of John Becker before merging to become *Everyday Practical Electronics* (*EPE*). John became *EPE's* technical editor.

Looking back over 25 years and speculating about life 25 years hence in 2014, I think November 1989's issue is the most thought-provoking and prescient issue of *PE* ever published. In 2014 I had the pleasure and privilege of writing our '50 Golden Year' anniversary celebrations, currently still downloadable as PDFs from **www.electronpublishing.com** under the 'Resources' tab. Thank you again for writing, Stephen!

More *Net Work* next month!

The author can be reached at:
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7-Band Mono or Stereo Equaliser

By John Clarke

These stereo or mono 7-Band Equalisers let you tailor the sound of your listening experience to suit your preferences. They can also be used to correct for room acoustics and deviations in loudspeaker response. The stereo version suits Hi-Fi systems, while the mono version is best for musical instruments or PA systems. Both feature extremely low noise and distortion, so they won't degrade your signal.

We know you like graphic equalisers, and the excellent *10-Band Stereo Graphic Equaliser* project published in the June and July 2018 issues was very popular. However, that design used slide pots and was quite complex and expensive to build. Slide pots are of course a great way to fabricate equalisers, but they do not lend themselves to being fitted into an existing amplifier. Plus, of course, for musical instrument use

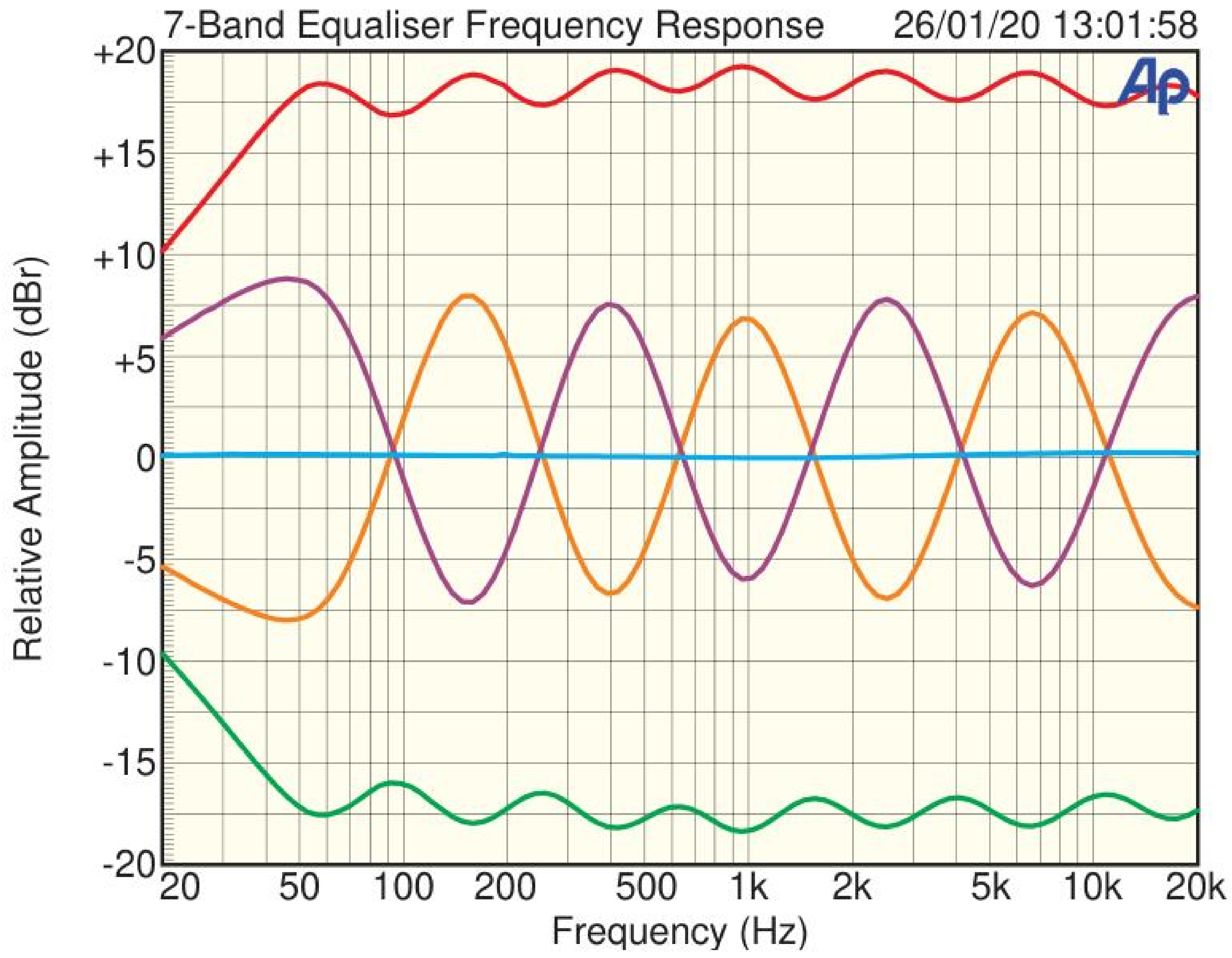


Fig.1: the blue curve shows the frequency response with all controls set to the centre position, with a flat response across the 20Hz to 20kHz band. The red and green curves show the response with all pots in the maximum boost setting (red) and with all pots in the maximum cut setting (green). Finally, the purple and orange curves show the response with alternate full cut and full boost between each band.

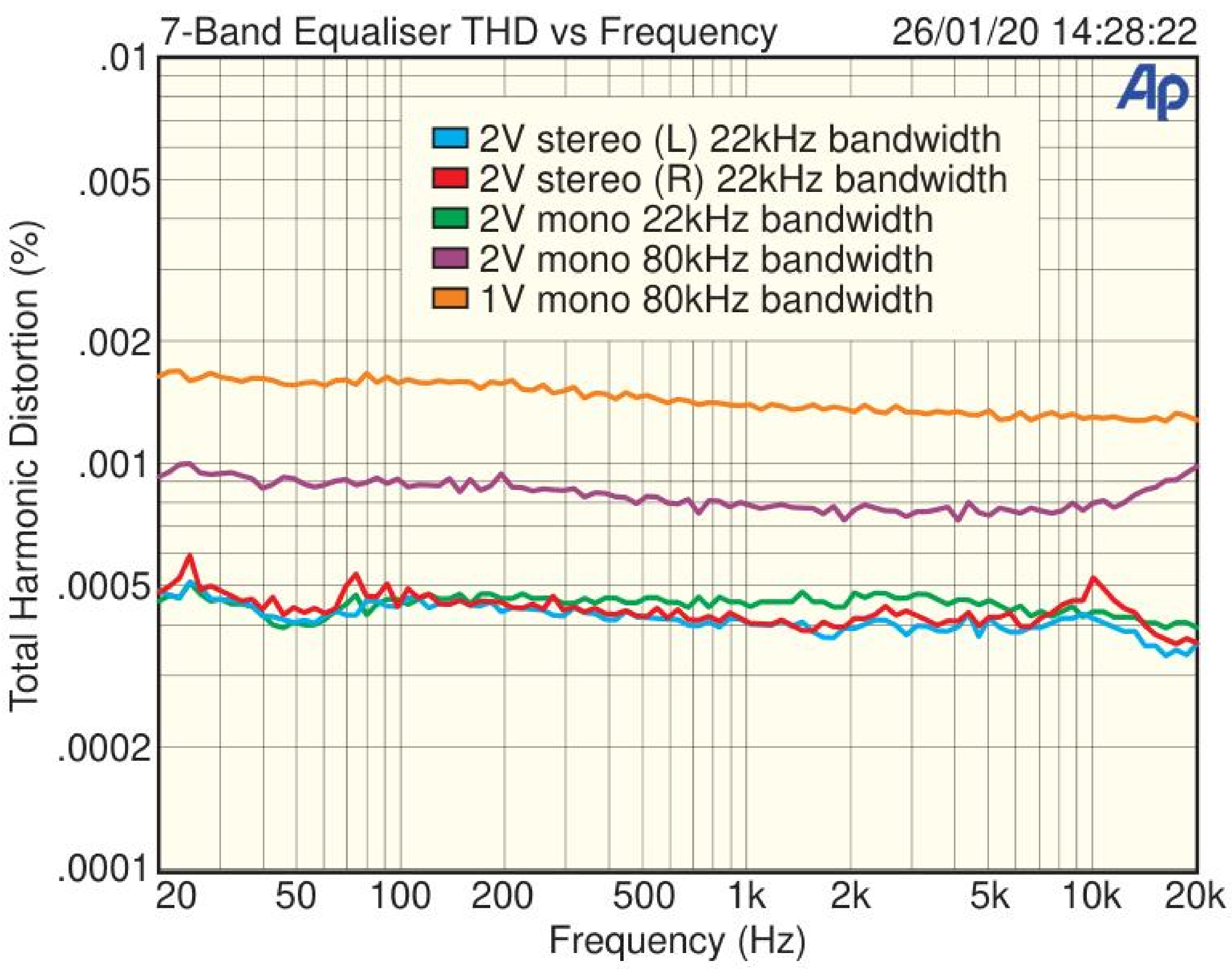


Fig.2: the harmonic distortion performance is excellent, with less than 0.0006% distortion at 2V from 20Hz to 20kHz measured with a 22kHz low-pass filter. Even with an 80kHz filter, distortion does not rise above 0.001% for a 2V signal. Noise was measured at 108dB down with 2V as a reference level. The 0.0005% distortion means that the noise and distortion measured is –106dB down in level from 2V.

you generally don't need the stereo capability. Therefore, we decided to come up with a new simpler design. It uses rotary pots, making it easy to mount in an existing amplifier (provided there is space), with the added bonus that they are cheaper than slide pots.

We have created a mono design, which will be of particular interest to musicians, but decided that while we were at it we might as well create a stereo version.

We've made sure the power supply is flexible: it can run from 15-16V AC, 30V AC with a centre tap, 18-20V DC or a regulated source of ±15V DC. Plus, we have ensured it has excellent performance, resulting in extremely low noise and distortion figures.

The different versions of the PCB for mono and stereo makes it easier to construct the version you want, and keeps the mono version as small as possible, keeping in mind the limited space that may be available for it to fit into existing amplifier enclosures. You'll be pleased to know the mono version of this *7-band Equaliser* is just 143 × 63.5mm, so with a bit of care and forward planning it should fit into many existing amps.

We're presenting both versions of the *7-band Equaliser* as bare PCBs. All the components mount onto these PCBs, including the input and output RCA sockets; you just need to organise a case and power supply.

Typical applications

The stereo version of our new *7-band Equaliser* can be connected to an amplifier or receiver in several ways. First, it can be connected in the 'Tape Monitor' loop that's still provided on many amplifiers and receivers.

Alternatively, the *7-band Equaliser* may be connected between the preamplifier and power amplifier. Some home theatre stereo receivers include preamp output and power amp input connectors for this purpose.

If you're using a separate preamp or input switcher, then the *7-band Equaliser* can be interposed between it and the power amplifier.

Or, if you only have a single sound source that has a nominal line level output level (anywhere between 500mV and 2V RMS), the *7-band Equaliser* input can be connected to that source output and preamplifier/amplifier input.

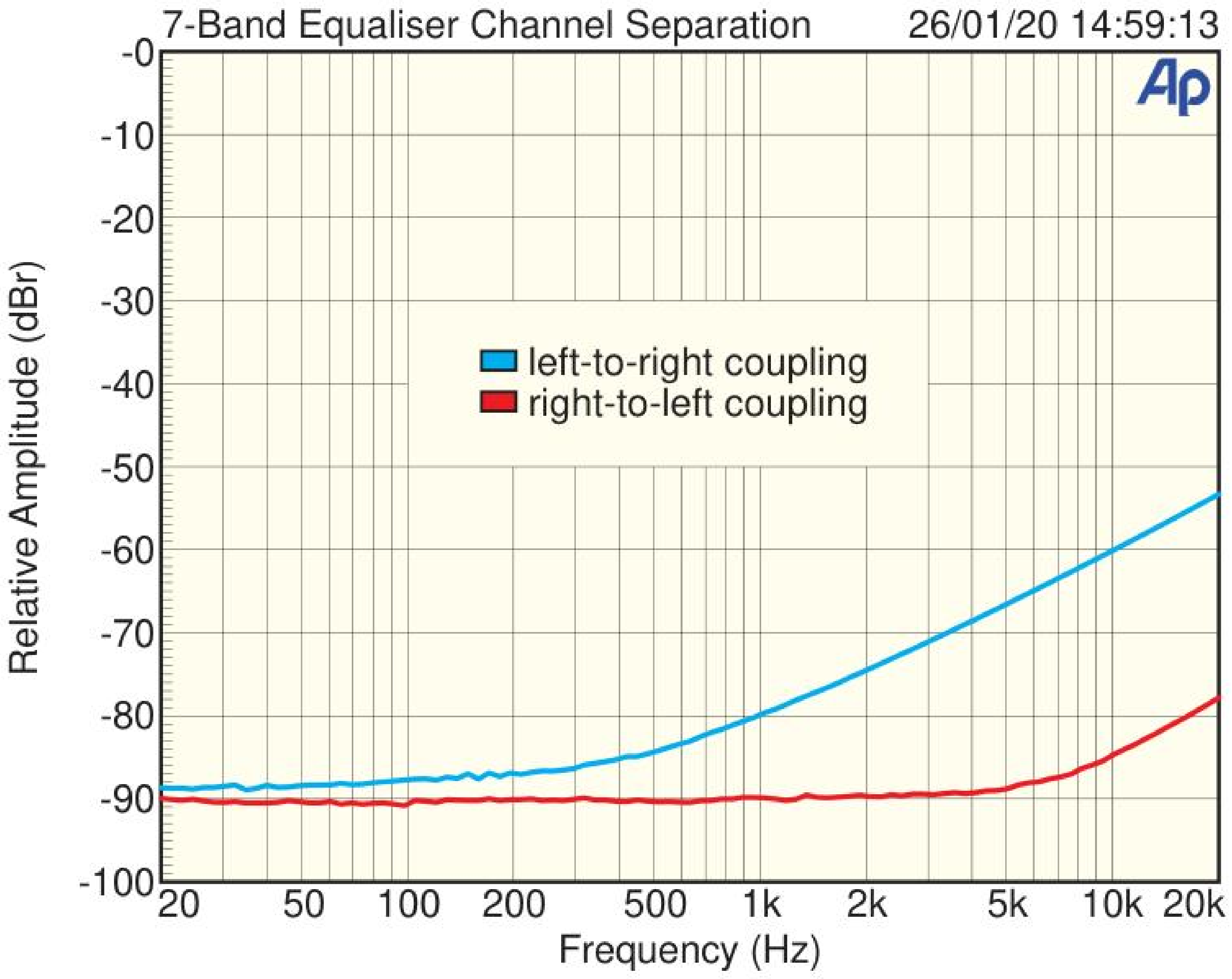


Fig.3: channel separation between left to right channel (blue) and right to left channels (red) show that separation is worse for the left to right coupling as frequency rises. These graphs are for the stereo version only. Separation figures obviously do not apply with the single-channel mono version.

For sound reinforcement use, you can connect the *7-band Equaliser* between the sound mixer output and amplifier input. In that case, you may need to add balanced-to-unbalanced and/or unbalanced-to-balanced converters on each channel. We published suitable designs for this in the September 2010 issue.

Performance

The overall performance is summarised in the *Features and specifications* panel and Figs.1-3. Its signal-to-noise ratio for a 2V RMS input is excellent at 108dB, and the distortion curves show that there is virtually no harmonic distortion present; the THD+N figures are consistent with pure noise.

Fig.1 has several coloured response curves which show what you can do with the controls. The blue curve shows the frequency with all controls set to the centre position, giving a ruler flat response over the audio band of 20Hz to 20kHz (it's tough to get it precisely flat due to pot variances, hence the slight amount of ripple visible).

The red and green curves show the response with all potentiometers in the maximum boost and cut settings, respectively. The mauve and orange curves show the response with the potentiometers alternately set for maximum boost and cut; these show the effective width of each band.

Note that you would never use an equaliser in these extreme settings as the result would sound very strange. Instead, you usually use comparatively small boost or cut settings. Subtlety, and 'a little goes a long way' is the approach to be taken with graphic equalisers.

For example, if your loudspeakers are a touch too bright in the 6kHz region, you might apply a couple of decibels of cut to the respective potentiometer. Or if you wanted to lift the bass response at around 60Hz, you could apply some amount of boost on the 63Hz band and get a much more subtle effect than would be possible with a conventional bass control.

The *7-band Equaliser's* overall performance is far beyond CD-quality audio. Fig.2 demonstrates that the harmonic distortion performance is limited by the residual noise 'floor' of the crucial gain stage in the circuit; that of IC9b and IC8a for the stereo version and IC5a in the mono version. With a realistic bandwidth of 20Hz-22kHz, the THD+N level is below 0.0006% for all audible frequencies.

Even with 80kHz measurement bandwidth, there is virtually no rise in distortion at higher frequencies. While the plot does seem to have a small rise up to 0.001% at 20kHz, other measurements we've taken under similar circumstances did not have such a rise, so we think it is probably a measurement artefact.

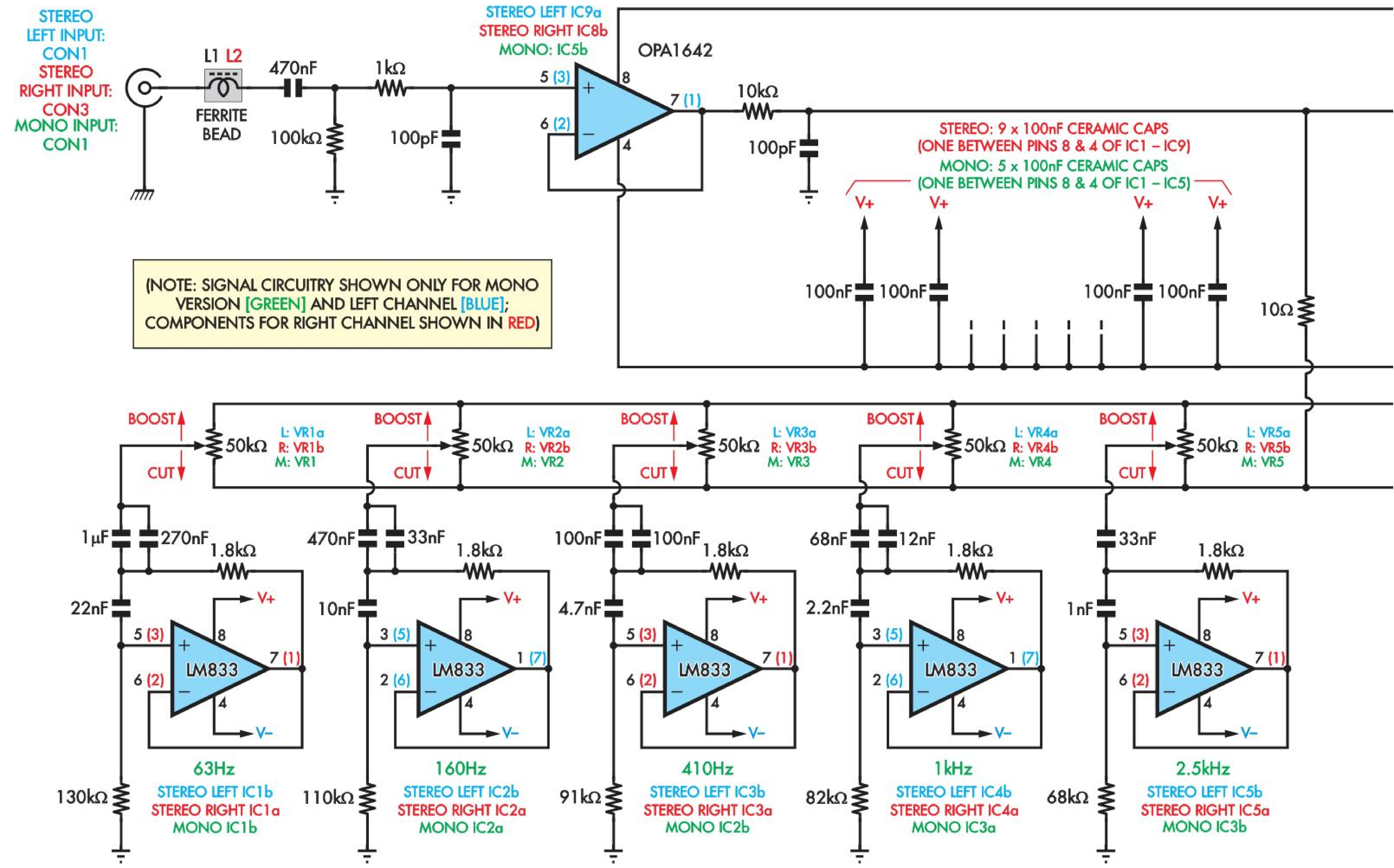
Suffice to say that the harmonic distortion introduced by this circuit is so far below that from a typical CD, DVD, Blu-ray or computer source that it will not adversely affect the sound quality of signals from such sources.

Finally, Fig.3 shows the channel separation for the stereo version of the equaliser. It exceeds 50dB at all frequencies and for both channels, and is at least 80dB for signals up to 1kHz.

Circuit details

Fig.4 shows the circuit of our *7-band Equaliser*. This is the complete circuit for the mono version, minus the power supply. The stereo version essentially duplicates all the parts for the second channel, except for the shared power supply and the use of dual-gang potentiometers in place of single-gang pots.

Labels in green apply to the mono version, in blue to the left channel portion of the stereo version and in red, to the right channel portion of the stereo version.


STEREO LEFT INPUT: CON1
STEREO RIGHT INPUT: CON3
MONO INPUT: CON1
L1 L2
FERRITE BEAD
470nF
100kΩ
1kΩ
100pF
STEREO LEFT IC9a
STEREO RIGHT IC8b
MONO: IC5b
OPA1642
5 (3)
6 (2)
8
4
7 (1)
10kΩ
100pF
STEREO: 9 x 100nF CERAMIC CAPS (ONE BETWEEN PINS 8 & 4 OF IC1 – IC9)
MONO: 5 x 100nF CERAMIC CAPS (ONE BETWEEN PINS 8 & 4 OF IC1 – IC5)
V+
100nF
10Ω
(NOTE: SIGNAL CIRCUITRY SHOWN ONLY FOR MONO VERSION [GREEN] AND LEFT CHANNEL [BLUE]; COMPONENTS FOR RIGHT CHANNEL SHOWN IN RED)
BOOST
CUT
50kΩ
L: VR1a R: VR1b M: VR1
L: VR2a R: VR2b M: VR2
L: VR3a R: VR3b M: VR3
L: VR4a R: VR4b M: VR4
L: VR5a R: VR5b M: VR5
1µF
270nF
470nF
33nF
100nF
100nF
68nF
12nF
33nF
1.8kΩ
22nF
10nF
4.7nF
2.2nF
1nF
LM833
V+
V–
63Hz
STEREO LEFT IC1b STEREO RIGHT IC1a MONO IC1b
160Hz
STEREO LEFT IC2b STEREO RIGHT IC2a MONO IC2a
410Hz
STEREO LEFT IC3b STEREO RIGHT IC3a MONO IC2b
1kHz
STEREO LEFT IC4b STEREO RIGHT IC4a MONO IC3a
2.5kHz
STEREO LEFT IC5b STEREO RIGHT IC5a MONO IC3b
130kΩ
110kΩ
91kΩ
82kΩ
68kΩ

7-Band Graphic Equaliser

Fig.4: the circuit for the mono version, minus the power supply (shown overleaf). The stereo version essentially duplicates all the parts for the second channel, except for the shared power supply and the use of dual-gang potentiometers in place of single-gang. Green labels apply to the mono version, blue to the left channel portion of the stereo version and red, to

When pin numbers are in red brackets, that is for the right channel, and the black pin number applies to the left channel and the mono version. Numbers in blue brackets are for the left channel, with the number for the mono version and right channel of the stereo version in black.

We have used dual low-noise/low-distortion LM833 op amps for the gyrators (described below). These have a noise level of 4.5nV/√Hz and very low distortion. These op amps use bipolar input transistors, with a typical input bias current of 500nA (1µA maximum). While this is not a problem for the gyrator circuits, as they are AC-coupled to the rest of the circuit, it is too high for the main signal path.

That's because, if such a current were to flow through the adjustment potentiometers, they could produce a noticeable scratching noise when rotated. So for the main signal path op amps (IC5 for the mono version and IC8/IC9 for the stereo version), we are using OPA1642 op amps which have JFET input transistors.

These have an ultra-low-distortion specification of 0.00005%, low noise at 5.1nV/√Hz and a 2pA typical (20pA maximum) input bias current. So their input bias current is typically 250,000-times less than the LM833s.

The following description is for the mono version, but the operation of the two channels in the stereo version is identical. The incoming signal is applied to RCA socket CON1. It passes through an RF-suppressing ferrite bead (L1) and is then AC-coupled to non-inverting input pin 5 of buffer op amp IC5b. The 1kΩ/100pF RC low-pass filter feeding that pin is to filter out RF signals that pass through FB1.

This signal is then fed, via another RF-suppression filter, to non-inverting input pin 3 of op amp IC5a. At first glance, this also appears to be operating as a buffer, albeit with a 10kΩ feedback resistor between its output pin 1 and inverting input (pin 2) rather than a direct connection.

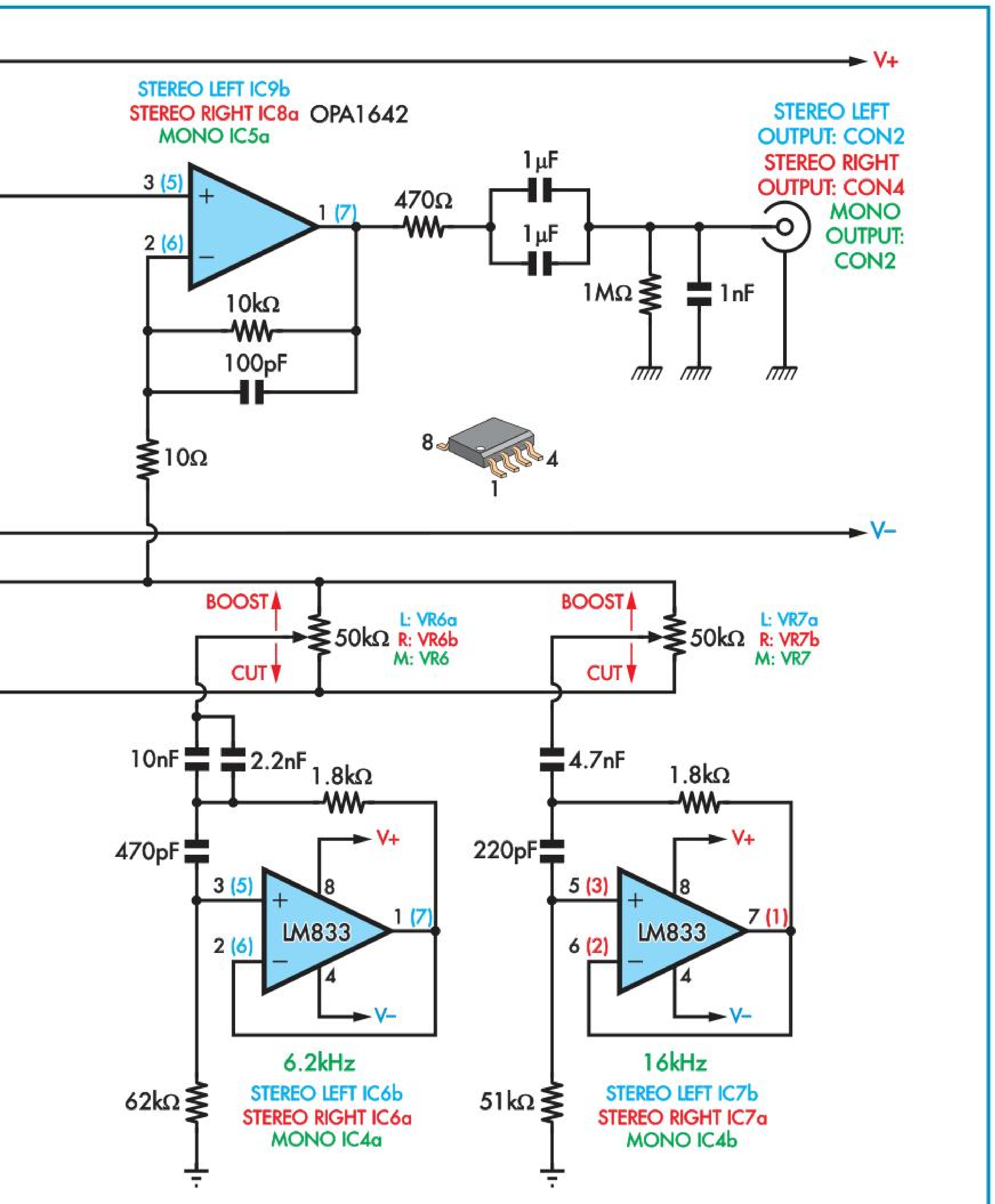
However, there are also seven 50kΩ linear potentiometers (VR1-VR7) connected across the two inputs of IC5a, and these change its operation.

The wipers of these pots are connected to seven op amp stages arranged along the bottom of the circuit diagram. These are all very similar, and are equivalent to series-resonant LC circuits built around the gyrators mentioned. There is one for each of the equaliser bands.

An important aid in understanding how this circuit works is to consider what happens when the pot wipers are centred. Whatever the impedance seen by the wiper in this case, the effect is divided equally between the two 25kΩ half-tracks of the pots, and so equally affects the non-inverting and inverting inputs (pins 3 and 2) of IC5a. Therefore, in this case, that particular stage does not affect the circuit's behaviour.

It is only when the pot wipers are moved away from the centre positions that they start having any effect on the signal.

While we said earlier that these seven circuits are equivalent to tuned LC resonant networks, you will note that there are no inductors present. That's because the close-tolerance, low-distortion inductors that would be required for good performance are very expensive and bulky, as well as being prone to hum pickup.



the right channel portion of the stereo version. Similarly, red pin numbers are for the right channel; the black pin number applies to the left channel and the mono version. Numbers in blue brackets are for the left channel, with the number for the mono version and right channel of the stereo version in black.

Therefore, as with virtually all equalisers designed over the last 50 years or so, we use gyrators instead. The gyrator is an op-amp-based circuit that simulates an inductor and can be connected in series with a capacitor to provide a resonant circuit.

Series-resonant circuit

To understand how these circuits work, let's consider a simplified version of the circuit with just one resonant circuit, as shown in Fig.5. As mentioned earlier, with the pot in its centre position, the impedance of the series network (C1+L1) affects both inputs of the right-hand op amp identically and so the frequency response is flat.

When the pot wiper moves to the boost end, more of the feedback from the output pin to the inverting input is shunted to ground by the series tuned circuit at frequencies around its resonance. Since its impedance is high at all other frequencies, this means that the feedback is only reduced over the narrow band centred around the resonance of the series tuned network.

As the feedback at these frequencies is reduced, the right-hand op amp will have to compensate by increasing its output signal swing at those frequencies, to return the feedback voltage to the same level as usual. So frequencies in that band will be boosted while others will be unaffected.

When the potentiometer is rotated towards the cut end, the tuned circuit instead shunts more of the input signals in its resonant band to ground. This results in a reduction of gain for the frequencies at or near the resonance of the series tuned network

Features and specifications

Channels	one (mono) or two (stereo)
Equaliser bands	seven (63Hz, 160Hz, 410Hz, 1kHz, 2.5kHz, 6.2kHz, 16kHz)
Boost/cut	approx ±12.5dB (bands overlap; see Fig.1)
SNR**	108dB (2V RMS), 102dB (1V RMS)
THD***	<0.0006%, 20Hz-20kHz, 20Hz-22kHz bandwidth (see Fig.2)
Input impedance	100kΩ ǁ 100pF
Output impedance	470Ω
Supply options	15-16V AC, 15-0-15V AC, 12-24V DC, ±15V DC
Channel separation*	>50dB, 20Hz-20kHz (880dB 20Hz-1kHz)
Other features	compact design, uses rotary pots for easy panel mounting

*Stereo version; ** signal-to-noise ratio; *** total hamonic distortion

As you would expect, the amount of boost or cut is proportional to the potentiometer setting, so intermediate settings give an intermediate level of signal boost or cut.

Gyrators

Fig.6 shows the circuit of a gyrator made with an op amp. It effectively transforms a capacitor into an inductor. In an inductor, the current lags the voltage by 90° while in a capacitor, the voltage lags the current by 90°.

Another way to explain this is that if you apply a large voltage step across a capacitor, a very high current flows initially, tapering off as the capacitor charges up.

By comparison, if you apply a large voltage step to an inductor, at first the current flow remains the same as it was before, but eventually the current flow increases as the magnetic field density increases.

To understand how the gyrator behaves like an inductor, consider an AC signal source (V_{IN}) connected to the input of Fig.6. This causes a current to flow through the capacitor and resistor R1. The voltage across R1 is thus proportional to the capacitor current. This voltage is fed to the op amp, which is connected as a voltage follower (or buffer).

The voltage at the output of the op amp thus tracks the voltage across R1. This then causes a current to flow through resistor R2. This current (I_{OUT}) adds to the input current I_C, the sum of which is the current drawn from the source and this lags the input voltage.

So, as far as the signal source is concerned, the gyrator appears like an inductor.

The formula to calculate the equivalent inductance is given by:

$$L = R1 \times R2 \times C2,$$

Note that in the above, L is in henries, $R1$ and $R2$ in ohms and $C2$ in farads.

Consider the effect of a large voltage step at the input; for example, say the input rises suddenly by 1V. This is initially coupled through C2 directly to the op amp, and so its output also rises by 1V, keeping the voltage across R2 the same. Thus, the current flow from the input changes very little initially.

The current flowing is just the current required to charge C2, and the value of C2 is typically chosen to minimise this.

As C2 charges, the voltage across R1 drops and so does the op amp output voltage, causing the current flowing from the input, through R2, to increase. As described above, this behaviour is much the same as if an inductor were connected instead of the gyrator.

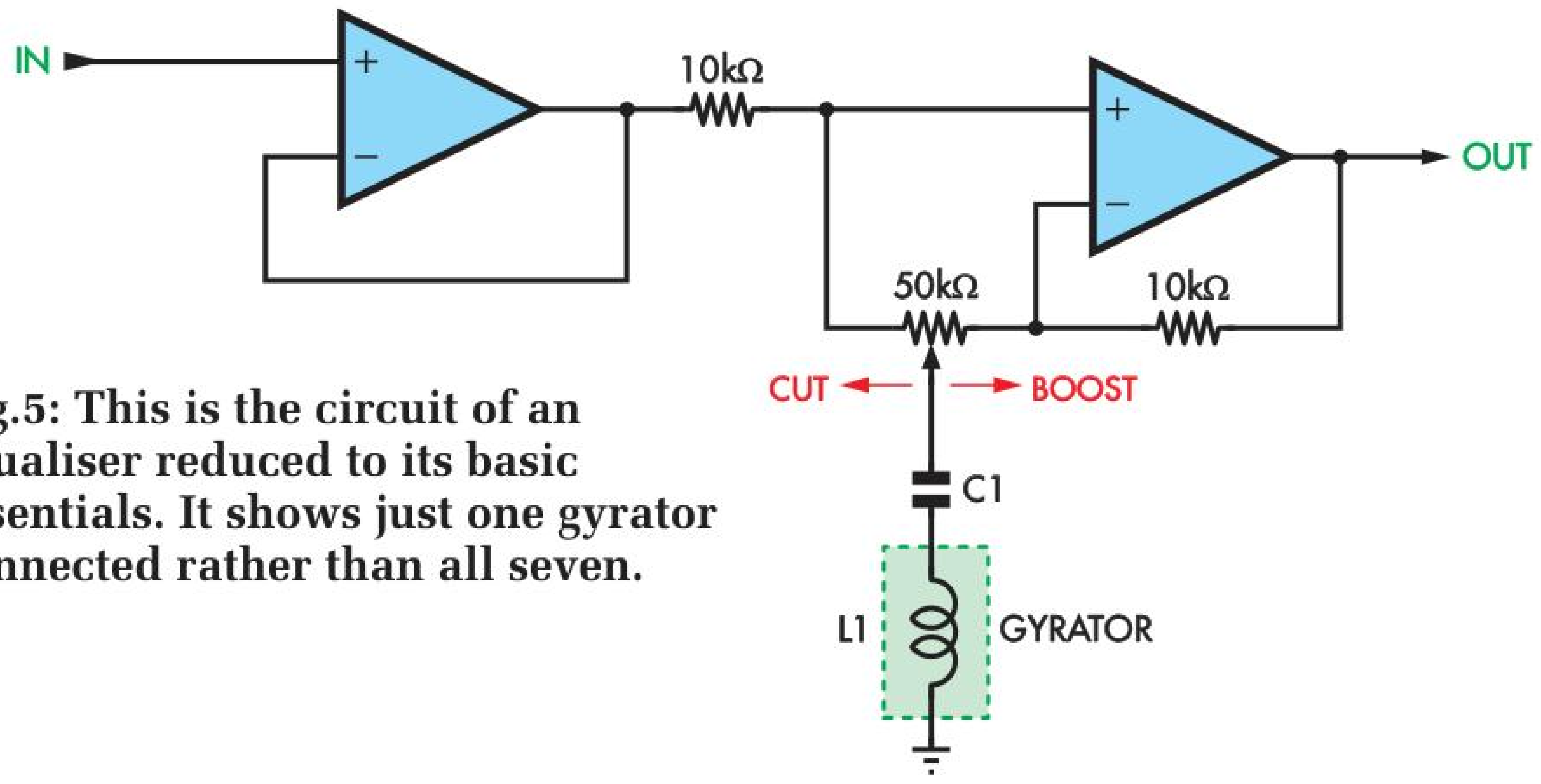


Fig.5: This is the circuit of an equaliser reduced to its basic essentials. It shows just one gyrator connected rather than all seven.

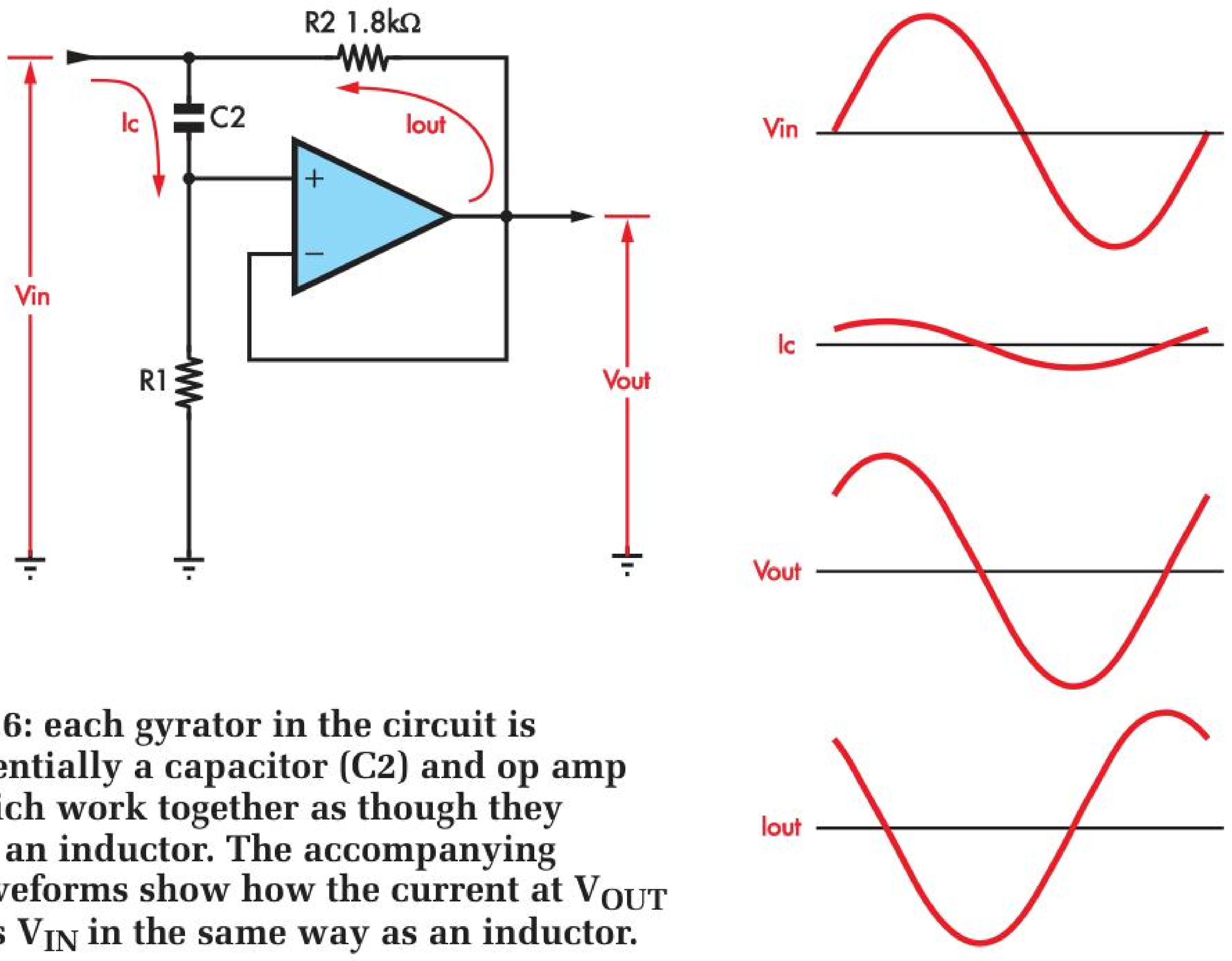


Fig.6: each gyrator in the circuit is essentially a capacitor (C2) and op amp which work together as though they are an inductor. The accompanying waveforms show how the current at V_{OUT} lags V_{IN} in the same way as an inductor.

To make the tuned LC circuit shown in Fig.5, all we need do is to connect a capacitor (C1) in series with the input to Fig.6. The result is a circuit with a dip in its impedance around a specific frequency. The values in our circuit set the bandwidth of each circuit to approximately 2.5 octaves.

Back to the Equaliser

So remember that we have one op amp buffer stage with seven pots connected inside its feedback loop. The wiper of each potentiometer is connected to one of a series-tuned circuit described above. Each is tuned to a frequency that is two and a half times that of the last (ie, about 1⅓ octaves higher), to provide seven adjustable frequency bands.

The output signal of the *7-band Equaliser* appears at output pin 1 of op amp IC5a, and this is fed via a 470Ω resistor and a 2µF DC blocking capacitor (using two parallel 1µF capacitors) to the output at CON2.

The 1MΩ resistor to ground sets the DC level for the output signal, while the 1nF capacitor shunts any out-of-band high-frequency noise to ground.

The 470Ω resistor determines the output impedance of the equaliser, while the 2µF output capacitor and 470nF input capacitor set the low frequency –3dB point of the entire circuit to about 4Hz.

Power supply

As already noted, there are three power supply options, and these are depicted in Figs.7(a)-(c).

You can use a centre-tapped 30V transformer, a 15-16VAC plugpack or a DC supply of up to 20V.

There are two ground/earth connections shown on the circuit with different symbols for each. One is the ground for the power supply, signal inputs and signal outputs, shown with an earth symbol (although it's only actually connected to earth if a mains transformer is used).

The second is the ground reference signal for the op amp circuitry, and this ground symbol is identical to the one used in Fig.4; indeed, all the points shown connected to ground in Fig.4 connect to the ground in Figs.7(a)-(c).

The two grounds are connected directly together when using an AC supply, via JP1. In this case, the power supply ground is connected to the centre tap of the transformer and the ground pins of REG1 and REG2. The AC from the transformer is converted to pulsating DC by the bridge rectifier formed by D1-D4 and filtered by two 470µF 25V capacitors, one for the positive supply and one for the negative.

The DC across these capacitors (with significant ripple) is then fed to regulators REG1 and REG2, which provide the +15V and –15V regulated supply rails to run the op amps.

The power LED (LED1) is powered from the +15V rail and its current is set to around 4mA by a 3.3kΩ resistor.

A 3.9kΩ resistor between 0V and the –15V supply rail provides a similar current flow in the negative supply rail, so that the supply rails collapse at the same rate when power is switched off. This prevents the op amps from oscillating as the supply capacitors discharge, and also prevents the output voltage from shifting markedly from 0V during power down.

You can use a 15-16VAC plugpack, as shown in Fig.7(b), instead of the centre-tapped transformer in Fig.7(a). This connects between 0V and AC1 at CON5, and diodes D1 and D4 form two half-wave rectifiers to derive the positive and negative rails. Diodes D2 and D3 are thus unused, and hence may be omitted.

The rest of the circuit works identically to the case in Fig.7(a); the only difference is that there will be twice as much ripple on the filtered but unregulated DC rails that form the inputs to REG1 and REG2.

For a DC supply, as shown in Fig.7(b), the positive voltage is applied to the AC1 terminal of CON5 and the negative voltage to the 0V terminal. Diode D4 provides reverse polarity protection; diodes D1-D3 may be omitted.

For input voltages below 18V, REG1 should be omitted and its input and output terminals shorted, so that the external supply runs the circuit directly via D4.

When using a DC supply, no negative rail is available so REG2 can be left off. A shunt is placed on header JP2 to connect the V– supply rail to the negative side of the external DC supply. JP1 is then positioned to connect the op amp grounds to a Vcc/2 half-supply rail.

This half-supply rail is required as all signals to the op amps now must be biased at half supply so that there will be a symmetrical signal swing between the positive DC supply and 0V.

This rail is derived using two series 10kΩ resistors across V+ and V–, with

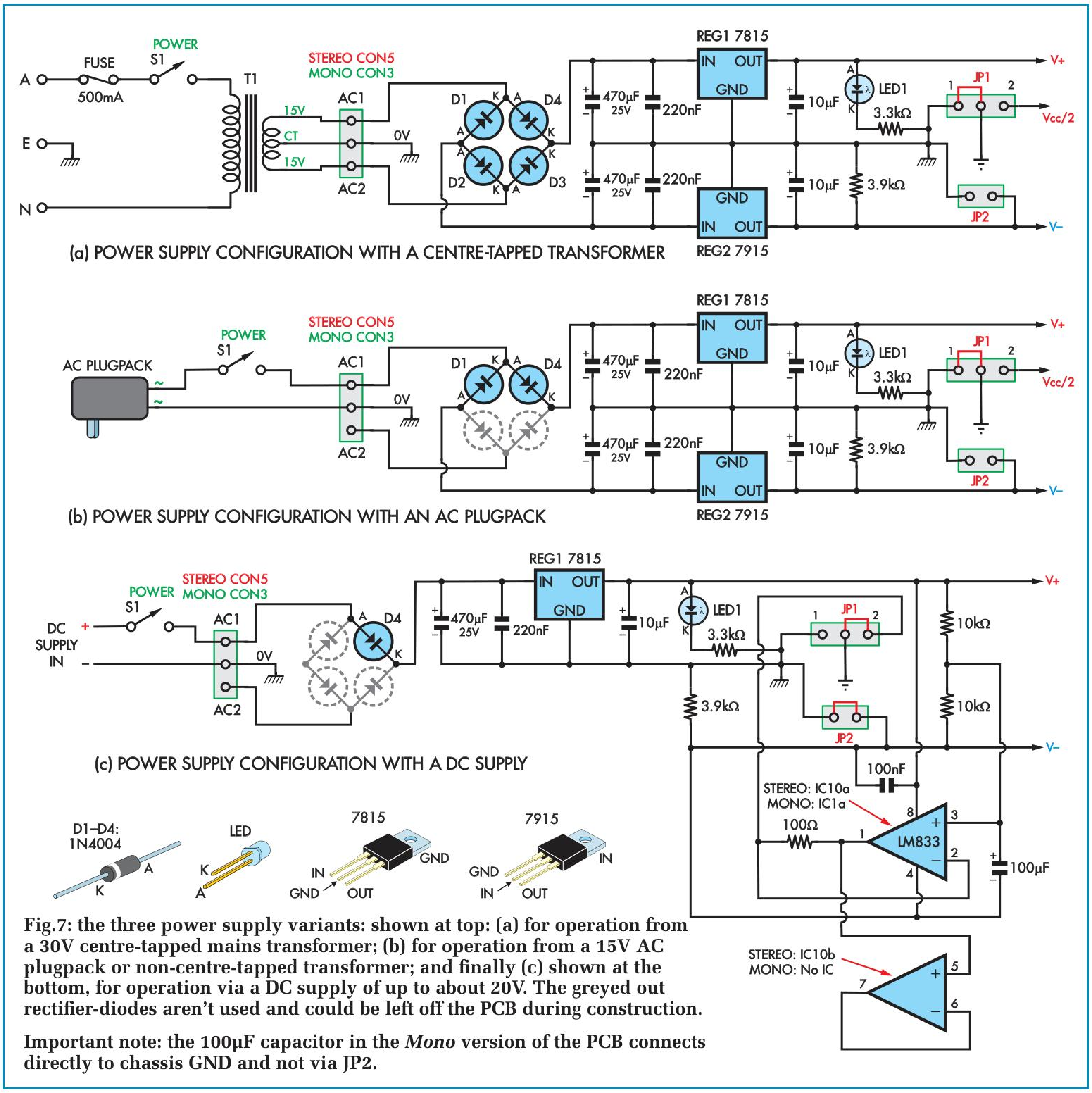

POWER
FUSE
S1
A
500mA
E
N
T1
15V
CT
15V
STEREO CON5
MONO CON3
AC1
AC2
0V
D1
D2
D3
D4
A
K
470µF 25V
220nF
REG1 7815
IN
OUT
GND
REG2 7915
10µF
LED1
3.3kΩ
3.9kΩ
JP1
JP2
1
2
V+
Vcc/2
V–
(a) POWER SUPPLY CONFIGURATION WITH A CENTRE-TAPPED TRANSFORMER
AC PLUGPACK
~
(b) POWER SUPPLY CONFIGURATION WITH AN AC PLUGPACK
DC SUPPLY IN
+
–
10kΩ
100nF
STEREO: IC10a
MONO: IC1a
100Ω
LM833
100µF
8
3
1
2
4
(c) POWER SUPPLY CONFIGURATION WITH A DC SUPPLY
STEREO: IC10b
MONO: No IC
5
7
6
D1–D4: 1N4004
LED
7815
7915
IN
GND
OUT

Fig.7: the three power supply variants: shown at top: (a) for operation from a 30V centre-tapped mains transformer; (b) for operation from a 15V AC plugpack or non-centre-tapped transformer; and finally (c) shown at the bottom, for operation via a DC supply of up to about 20V. The greyed out rectifier-diodes aren't used and could be left off the PCB during construction.

Important note: the 100µF capacitor in the *Mono* version of the PCB connects directly to chassis GND and not via JP2.

the centre connection bypassed to V– with a 100µF capacitor, to reject supply ripple. Op amps lC10a (stereo version) and lC1a (mono version) buffer this half-supply rail.

The spare op amp (IC10b) is not used in the stereo version, but is connected as a buffer from IC10a's output. This is to prevent the op amp inputs floating and causing oscillation. The mono version uses an existing spare op amp (IC1a) for the Vcc/2 buffer, so there is no unused op amp half.

Construction

The stereo version of the equaliser is built using a double-sided PCB coded 01104202, measuring 157 × 86mm. Its component overlay diagram is shown in Fig.8. The mono version is built on a different double-sided PCB, coded 01104201, measuring 143 × 63.5mm. If building this version, refer to the mono overlay diagram, Fig.9.

Both versions of the PCBs are available from the *PE PCB Service.*

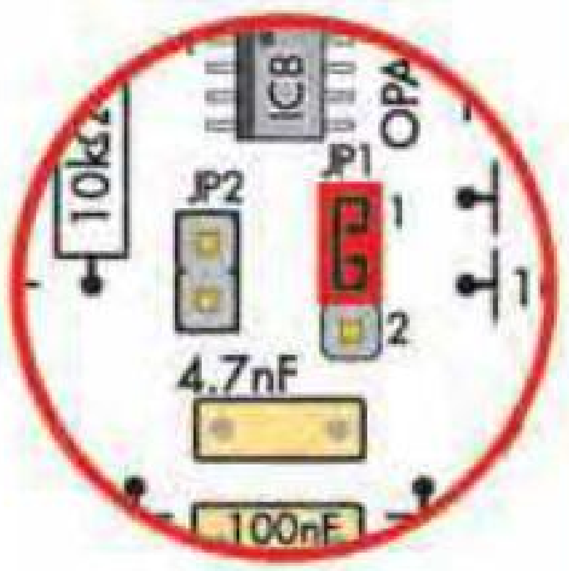
Note that if you are building the stereo version and you are not using a DC supply, op amp IC10 does not need to be installed. That's because it's only used to buffer the Vcc/2 supply rail required for the DC power configuration.

Begin circuit construction by fitting the surface-mount ICs. These are IC8 and IC9 for the stereo version, and just IC5 for the mono version. (This type of op amp is not available in a through-hole package).

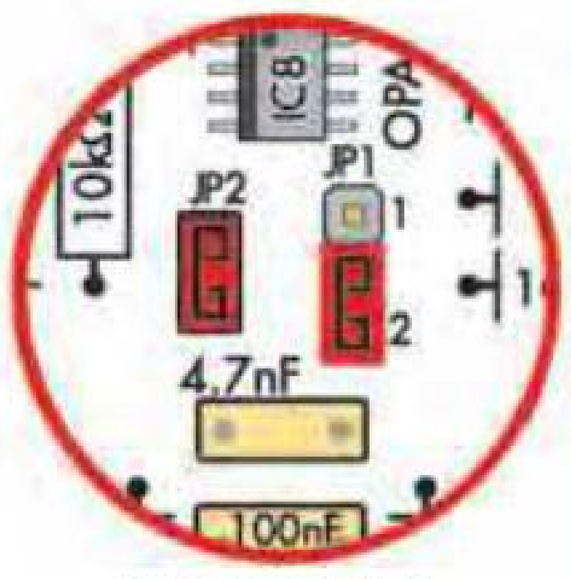
In each case, make sure you have oriented the IC correctly; a white line is printed on the top of the package between pins 1 and 8. Position the IC over the PCB pads and solder one corner pin. Check its alignment and re-melt the solder if you need to adjust its position. When the IC is aligned correctly, solder the remaining seven pins. Do make sure that there are no solder bridges between any of the adjacent pins.

However, keep in mind that the following pins are joined on the PCB, so bridges between them do not matter: (stereo version) pins 1 and 2 of IC9 and pins 6 and 7 of IC8; (mono version) pins 6 and 7 of IC5.

Continue by installing the resistors. It's a good idea to check their values using a multimeter set to read ohms to be safe. Then fit the two ferrite beads by feeding a resistor lead offcut through each bead before soldering them in place.


10kΩ
JP2
IC8
OPA
JP1
1
2
4.7nF
100nF

Jumper settings
for AC supply


10kΩ
JP2
IC8
OPA
JP1
1
2
4.7nF
100nF

Jumper settings
for DC supply

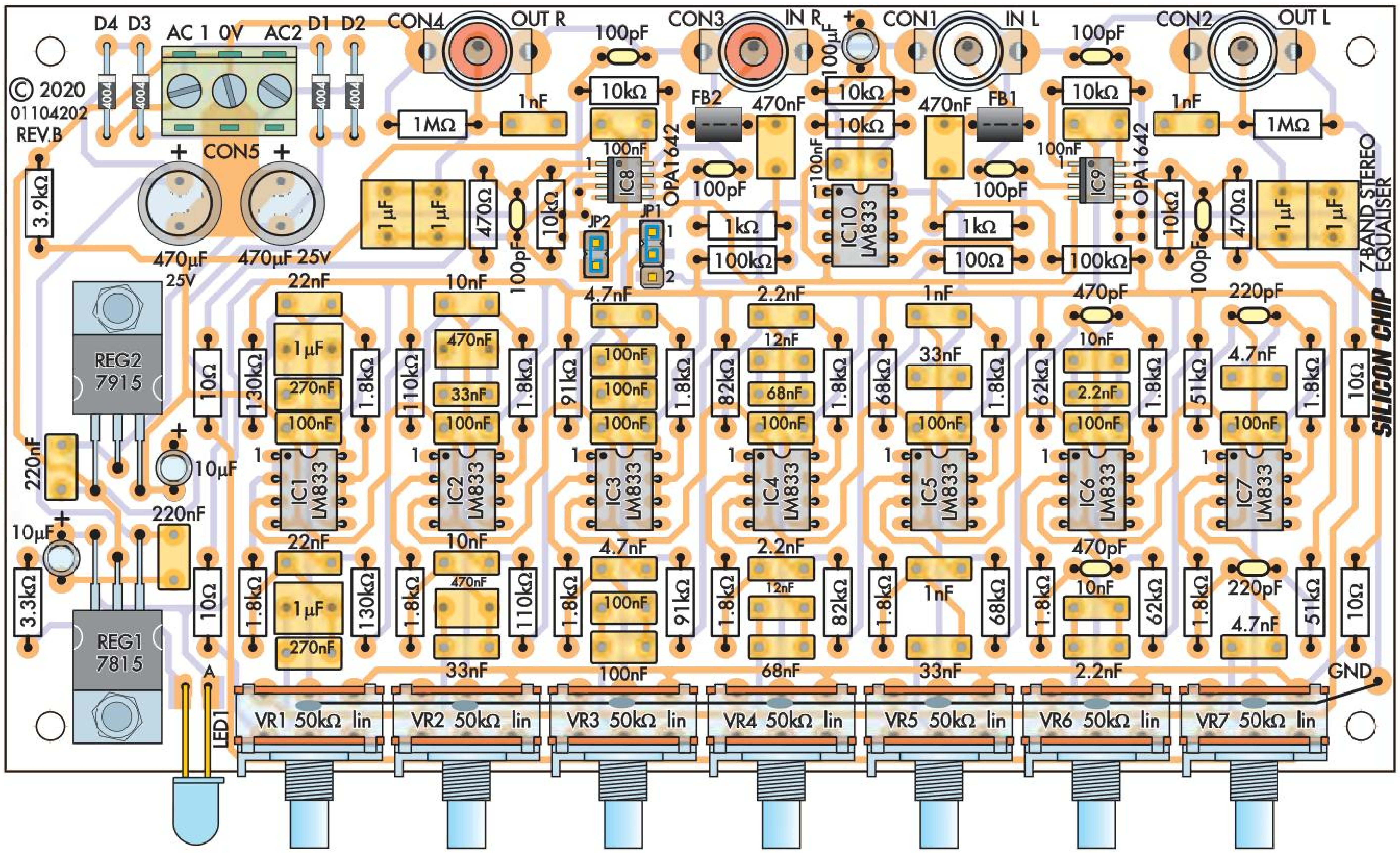
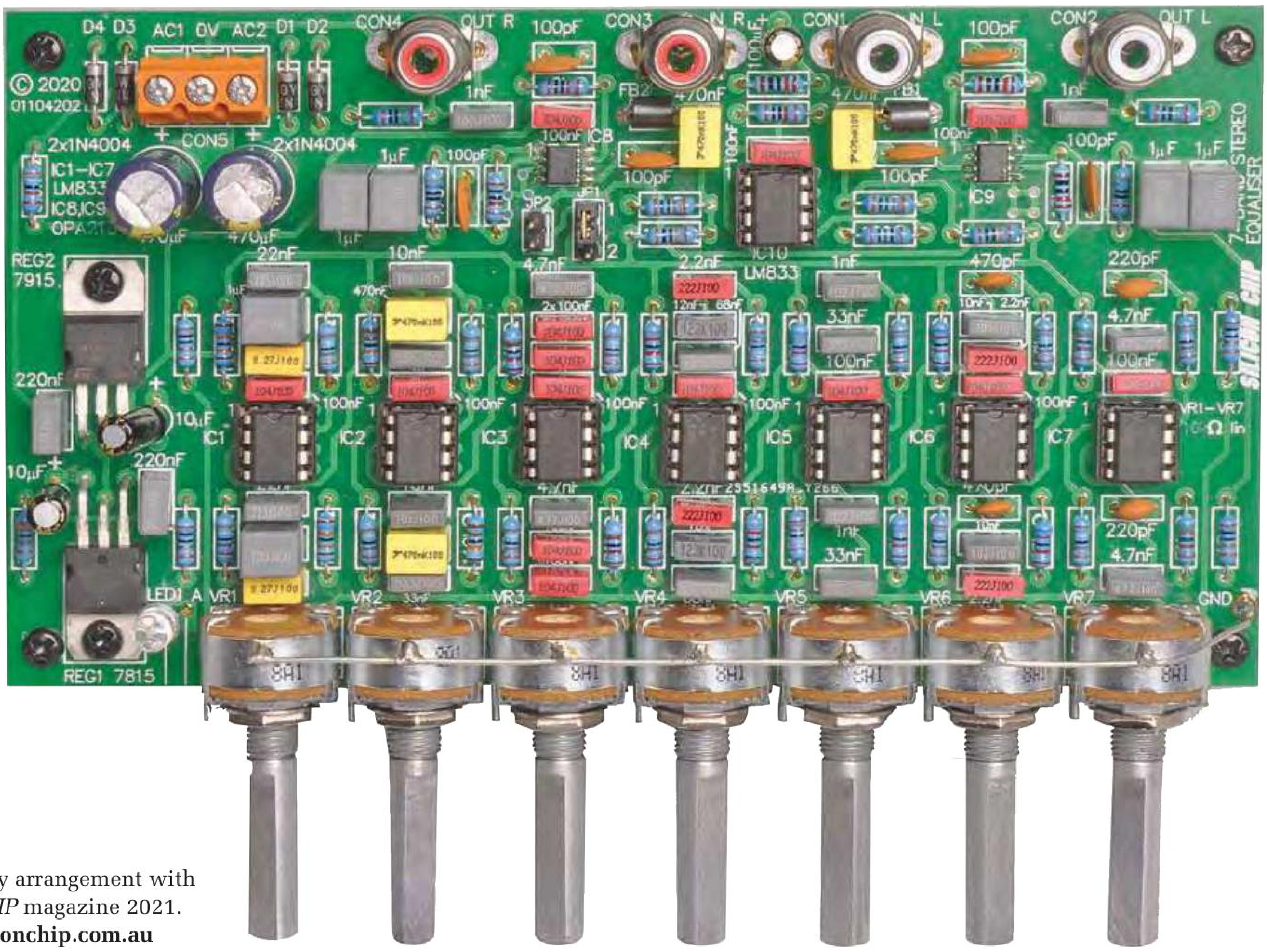

D4 D3
AC 1 0V AC2
D1 D2
CON4
OUT R
CON3
IN R
CON1
IN L
CON2
OUT L
© 2020
01104202
REV.B
CON5
470µF 25V
470µF 25V
REG2 7915
REG1 7815
IC8 OPA1642
IC9 OPA1642
IC10 LM833
IC1 LM833
IC2 LM833
IC3 LM833
IC4 LM833
IC5 LM833
IC6 LM833
IC7 LM833
FB1
FB2
JP1
JP2
LED1
A
GND
VR1 50kΩ lin
VR2 50kΩ lin
VR3 50kΩ lin
VR4 50kΩ lin
VR5 50kΩ lin
VR6 50kΩ lin
VR7 50kΩ lin
7-BAND STEREO EQUALISER
SILICON CHIP

Fig.8: the overlay diagram (and matching photo below) for the stereo version of the equaliser. Take care to orient the ICs, diodes, electrolytic capacitors and the regulators correctly. Before you solder the grounding wire to all pots (also see photo below) you will probably have to scrape or file some of the passivation off the pot bodies, otherwise soldering may be very difficult. This wire connects to the PCB at the 'GND' pad at the right side.



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Diodes D1-D4 can be mounted now; make sure they are oriented correctly. As shown in Figs.7(b) and (c), if you are powering the unit from a plugpack or DC supply, you may omit some of these diodes, although it doesn't hurt to fit them all; it keeps your powering options open.

Continue by installing the remaining ICs. These are in dual-in-line packages, so you can use IC sockets if you prefer. This makes it easier to swap them later, or replace a failed op amp; however, the sockets themselves can be a source of problems due to corrosion in the metal which contacts the IC pins.

Regardless of whether you are soldering sockets or ICs to the board, make sure they're all oriented correctly.

Now fit the ceramic and MKT polyester capacitors, which are not polarised, followed by the electrolytic capacitors, which are. Their longer leads must go into the holes marked with the '+' symbols on the PCB; the striped side of each can indicates the negative lead.

LED1 also needs to be mounted with the correct orientation. Its longer lead is the anode, and this goes to the pad marked 'A' on the PCB. Fit it with the top of the lens 12mm above the PCB. The leads can be bent over so the LED is horizontal later, when installing the *7-band Equaliser* into its case.

When mounting the RCA sockets, the white ones are for the left channel and the red ones are for the right channel. The 3-way screw terminal (CON5 for the stereo version or CON3 for the mono version) can then be installed with its wire entry holes towards the edge of the PCB.

Fit regulators REG1 and REG2 next. These are mounted horizontally, with the tabs secured using screws and nuts. If you are using a DC supply for the equaliser, then REG2 and associated components do not need to be installed (this includes the 470µF and 220nF capacitors at REG2's input and the 10µF capacitor at the output).

If you are unsure of which component to leave off, fit them all. This means the board will work if you later decide to use an AC power source.

For the DC supply version, use a 7815 for REG1 if the supply is between 18V and 24V (25V absolute maximum). If the supply is 15-18V, use a 7812 regulator. For 12-15V, dispense with REG1 and instead fit a wire link between the IN and OUT terminals (the two outer pads). In this case, the incoming DC supply will need to be reasonably free of noise and ripple for good performance

We don't recommend using a supply lower than 12V as the op amp signal swing becomes limited.

Once you've figured out which regulators to install, start by bending their leads to fit into the holes in the PCB, with the tab holes lined up with the PCB mounting holes. Attach the regulator bodies with screws and do them up tight *before* soldering and trimming the leads.

Mount jumper header JP1 and JP2 next. For an AC supply, insert the jumper link on JP1 in position 1 and leave JP2 open. For a DC supply, insert the jumper link on JP1 in position 2 and also fit a jumper link on JP2.

All that's left now are the potentiometers. The pot bodies should be grounded using tinned copper wire that is soldered to each pot body and then to the GND terminal point (see photos). To do this, you will need to scrape off some of the passivation coating on the top of each pot body before soldering them to the board.

Selecting the knobs

You must use knobs 16mm in diameter or less, and this includes any flange/skirt at the base (ie, measure the maximum diameter).

Note that some potentiometers have a D-shaped shaft while others are fluted, so you will need to make sure that you purchase knobs which match your shafts. Also, keep in mind that knobs for 6mm (metric) shafts will not fit pots with 1/4-inch (6.35mm) shafts.

Whether you use a knob with a skirt depends on how you will be mounting the potentiometers. Knobs with skirts are designed to cover the potentiometer nut, if this is exposed on the mounting panel.

If the pot is mounted on a recessed panel, it is not necessary to use knobs with skirts. Suitable knobs for the 1/4-inch D-shaft potentiometers from

Parts list – 7-band Graphic Equaliser

(Parts common to both versions)
7 knobs to suit pots (16mm maximum diameter) – see text
1 3-way PCB-mount screw terminal, 5.08mm pin spacing
  (CON3 [mono]/CON5 [stereo])
1 3-way header, 2.54mm spacing (JP1)
1 2-way header, 2.54mm spacing (JP2)
2 jumper shunts/shorting blocks (JP1,JP2)
2 M3 x 6mm panhead machine screws and nuts
1 PC stake
1 150mm length of tinned copper wire
1 power supply (see text)

Semiconductors
4 LM833P dual low-noise op amps, DIP-8 (IC1-IC4)*
1 OPA1642AID JFET-input op amps, SOIC-8 (IC5/IC8)*
  [Digi-Key, Mouser, RS Components]
1 7815 +15V 1A linear regulator (REG1)
1 7915 –15V 1A linear regulator (REG2)
4 1N4004 400V 1A diodes (D1-D4)
1 5mm or 3mm LED (LED1)

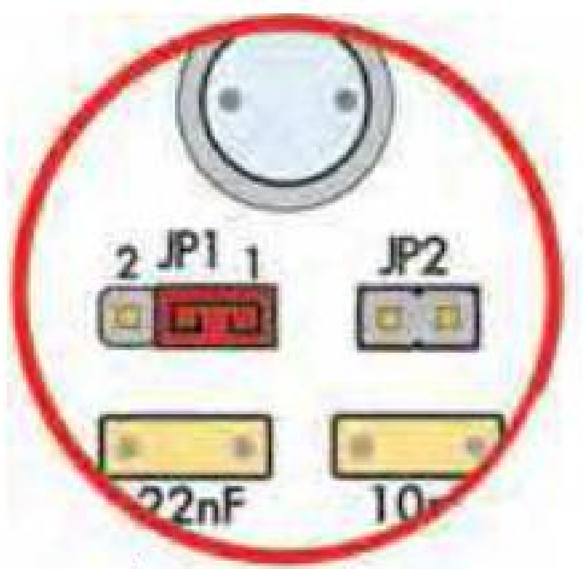
Capacitors
2 470µF 25V PC electrolytic
1 100µF 16V PC electrolytic
2 10µF 16V PC electrolytic
3 1µF MKT polyester*
2 470nF MKT polyester*
1 270nF MKT polyester*
2 220nF MKT polyester
7 100nF MKT polyester*
1 68nF MKT polyester*
2 33nF MKT polyester*
1 22nF MKT polyester*
1 12nF MKT polyester*
2 10nF MKT polyester*
2 4.7nF MKT polyester*
2 2.2nF MKT polyester*
2 1nF MKT polyester*
1 470pF ceramic*
1 220pF ceramic*
3 100pF ceramic*

Note: quantities shown are for the mono version. All components marked with an asterisk (*) should have quantities doubled for the stereo version

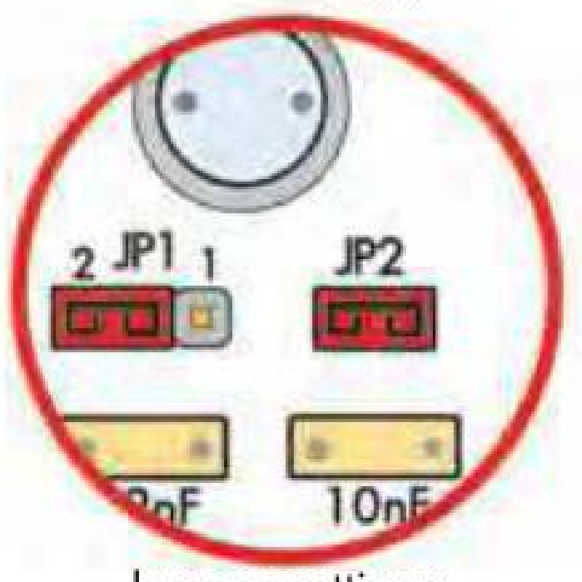
Resistors (all 1/4W, 1% metal film)
2 10Ω* 1 100Ω 1 470Ω* 1 1kΩ* 7 1.8kΩ* 1 3.3kΩ
1 3.9kΩ 4 10kΩ 1 51kΩ* 1 62kΩ* 1 68kΩ* 1 82kΩ*
1 91kΩ* 1 100kΩ* 1 110kΩ* 1 130kΩ* 1 1MΩ*

Extra parts for the stereo version
1 double-sided PCB coded 01104202, 157 x 86mm, available
  from the PE PCB Service
7 50kΩ dual-gang linear 16mm potentiometers (VR1-VR7)
2 vertical PCB-mount white RCA sockets [Altronics P0131]
  (CON1,CON2)
2 vertical PCB-mount red RCA sockets [Altronics P0132]
  (CON3,CON4)
2 5mm-long ferrite beads (FB1,FB2)
2 10kΩ 1/4W 1% metal film resistors

Extra parts for the mono version
1 double-sided PCB coded 01104201, 143 x 63.5mm,
  available from the PE PCB Service
7 50kΩ single-gang linear 16mm potentiometers (VR1-VR7)
1 vertical PCB-mount white RCA socket [Altronics P0131] (CON1)
1 vertical PCB-mount red RCA socket [Altronics P0132] (CON2)
1 5mm-long ferrite bead (FB1)


2 JP1 1
JP2
22nF
10

Jumper settings
for AC supply


2 JP1 1
JP2
nF
10nF

Jumper settings
for DC supply

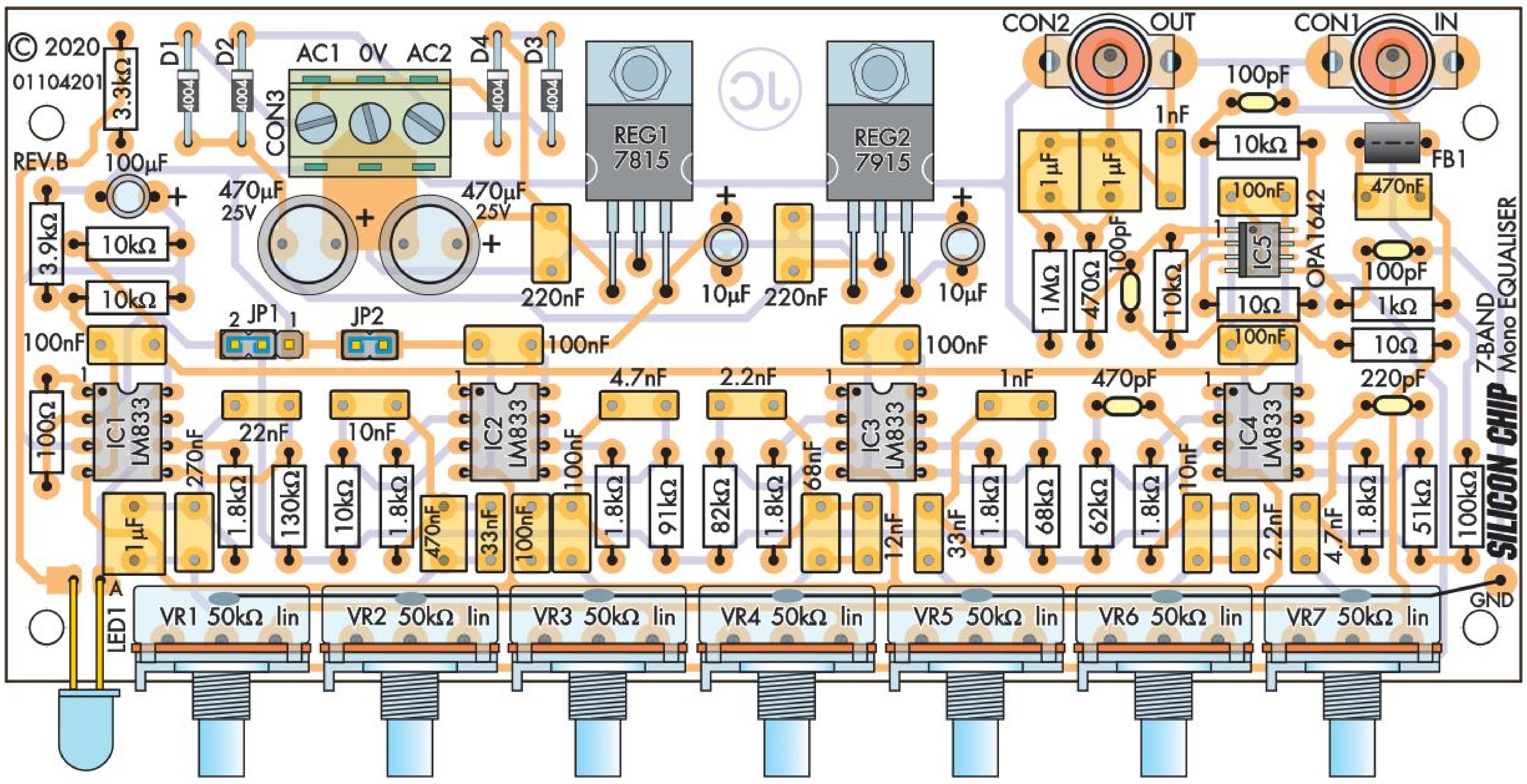
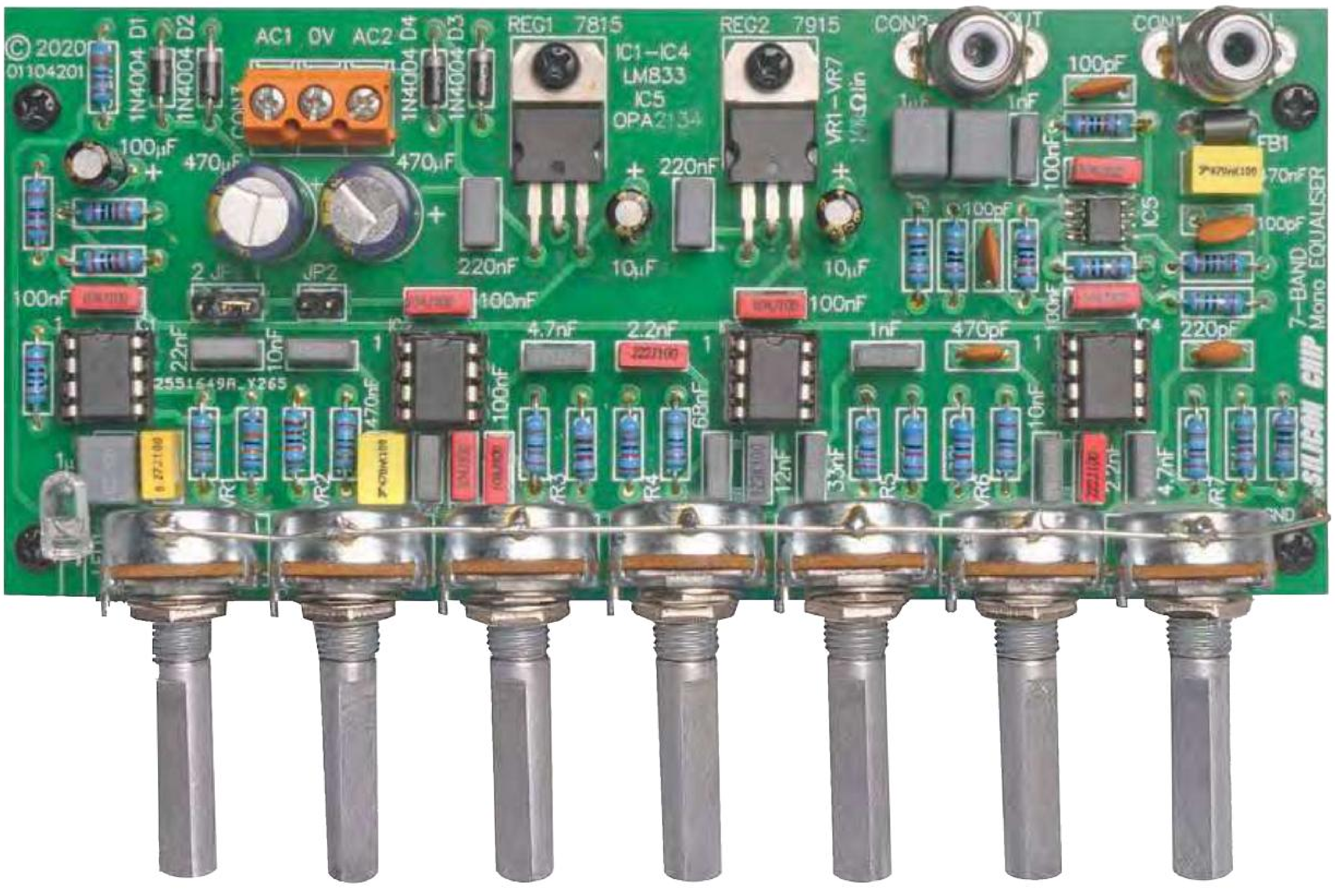

© 2020
01104201
REV.B
3.3kΩ
D1
D2
4004
AC1 0V AC2
CON3
D4
D3
REG1 7815
REG2 7915
CON2
OUT
CON1
IN
100pF
1nF
10kΩ
FB1
100nF
470nF
1µF
1µF
IC5
OPA1642
7-BAND Mono EQUALISER
100µF
470µF 25V
470µF 25V
3.9kΩ
10kΩ
10kΩ
220nF
10µF
220nF
10µF
1MΩ
470Ω
100pF
10kΩ
10Ω
1kΩ
10Ω
100nF
JP1
JP2
100nF
100nF
100nF
220pF
4.7nF
2.2nF
1nF
470pF
100Ω
IC1 LM833
IC2 LM833
IC3 LM833
IC4 LM833
270nF
22nF
10nF
1.8kΩ
130kΩ
10kΩ
1.8kΩ
470nF
33nF
100nF
1.8kΩ
91kΩ
82kΩ
1.8kΩ
68nF
12nF
33nF
1.8kΩ
68kΩ
62kΩ
1.8kΩ
10nF
2.2nF
4.7nF
1.8kΩ
51kΩ
100kΩ
SILICON CHIP
1µF
A
LED1
VR1 50kΩ lin
VR2 50kΩ lin
VR3 50kΩ lin
VR4 50kΩ lin
VR5 50kΩ lin
VR6 50kΩ lin
VR7 50kΩ lin
GND

Fig.9: the overlay diagram (again with matching photo below) for the mono version of the equaliser. The mono version would best suit musical instruments or a public address amplifier. It's a little simpler than the stereo version and the PCB is smaller. The most obvious difference (but not the only one!) is the use of single-gang pots instead of dual-gang. Note our comments on the stereo overlay (Fig.8) regarding soldering the grounding wire to the pot bodies.



Jaycar or Altronics are Jaycar Cat HK7760 and Altronics Cat H6040. Both have skirts.

More expensive (and more classy) aluminium knobs without a skirt are also available; for example, Jaycar Cat HK7020 (silver) and HK7009 (black), plus Altronics Cat H6331 (silver) and H6211 (black).

Altronics also has the black Cat H6106 and coloured cap series, Cat H6001-H6007.

All of the above are grub screw types. These allow the knob to be secured with the pointer opposite the flat portion of the D-shaped shaft. Knobs with an internal D-shaped hole should not be used unless the pointer can be reoriented. Fixed pointer knobs generally point in the direction of the flat portion of the D-shaped shaft, which is the opposite of what we require.

Initial testing

You can now power up the *7-band Equaliser* board to test for voltage at the op amps. Refer to Figs.7(a)-(c) for how to wire up the power supply. If you are using a mains transformer, make sure everything is fitted in a properly earthed metal box with tidy and suitably insulated mains-rated wiring. *You must not attempt this if you don't have experience in building mains-based projects.*

If fitting the *7-band Equaliser* into an existing chassis and using the pre-installed transformer, that transformer must be capable of supplying the extra current drawn by the equaliser circuit. This is 70mA maximum for the stereo version and 45mA for the mono version. That's low enough that it's unlikely it will cause any problems.

Power up the circuit and check that LED1 lights, then measure the DC voltage between pins 4 and 8 of the op amps. This should be close to 30V (29.5V-30.5V) if you are using the AC supply.

For the DC supply version, check that this voltage is close to 15V (14.75-15.25V) if you've fitted a 7815, or 12V (11.75-12.25V) if you've fitted a 7812. If REG1 is linked out, you can expect about 0.7V less than the incoming supply voltage.

The voltage between pin pairs 4 and 1, and 4 and 7 of each op amp should show half the supply voltage. In other words, this voltage should be 7.5V or thereabouts if you measured 15V between pins 4 and 8.

All that's left then is to centre the pots, connect a signal source to the input and an amplifier to the output and check that the sound from the amplifier is clean and undistorted. Experiment by rotating the various knobs and check that you can vary the frequency response as expected.

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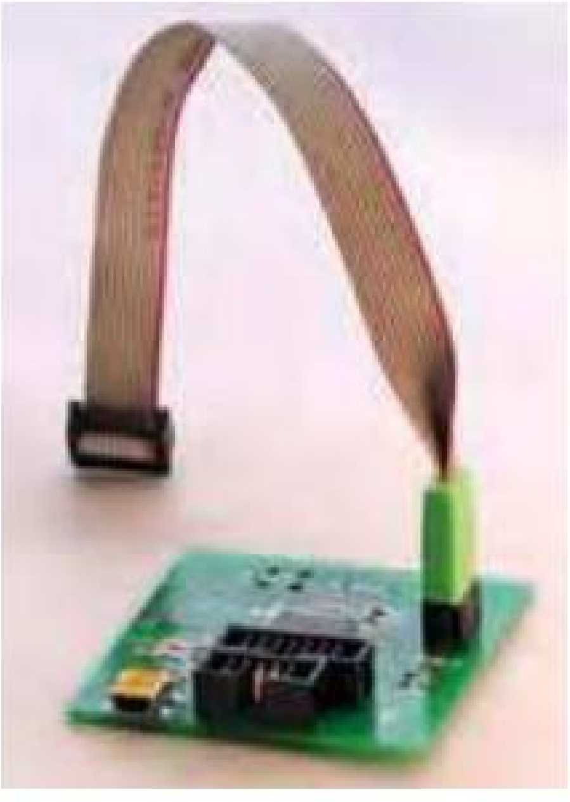

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TOUCHSCREEN CAR ALTIMETER

By
Peter Bennett

Air Temp: 19.2degC
RelHumid: 48%
Air Pres: 1008.3hPa
Altitude: 3000
m above QNH
TOUCH TO CHANGE MODE OR UNITS

This modified version of Jim Rowe's *Touchscreen Altimeter* is optimised for use in a car, truck or other land-based vehicle, rather than a glider or ultralight aeroplane. The hardware has been simplified and adapted to be powered from the vehicle, while the software has been updated to make its readings more accurate on a typical driving trip.

This is a modified version of the *Touchscreen Altimeter and Weather Station* project from December 2018, to better suit car use.

You might be wondering why I want an altimeter in my car. I find it interesting to know how high I am when driving in the mountains, especially when stopping at lookouts (some have their altitude posted, but not all).

Also, engine performance is reduced at altitude, so the information may do more for you than just satisfy your meteorological curiosity.

The power output of naturally aspirated petrol engines drops by about 3-4% per 300m (1000ft); turbocharged engines are less affected, but can still lose some power due to the thinner air at higher altitudes, depending on their particular design.

In a motor vehicle, the *Car Altimeter* can be powered from the vehicle's accessory socket, so there is no need for the internal battery used in the original design. This means that we can fit all the hardware in a single UB3 Jiffy box, with an exhaust fan to remove the heat generated by the display, avoiding the need to mount the sensors in a separate box.

In this design, power is supplied via a USB cable. Many modern cars have USB charging sockets. If yours doesn't, you can use a USB charger plugged into the accessory socket.

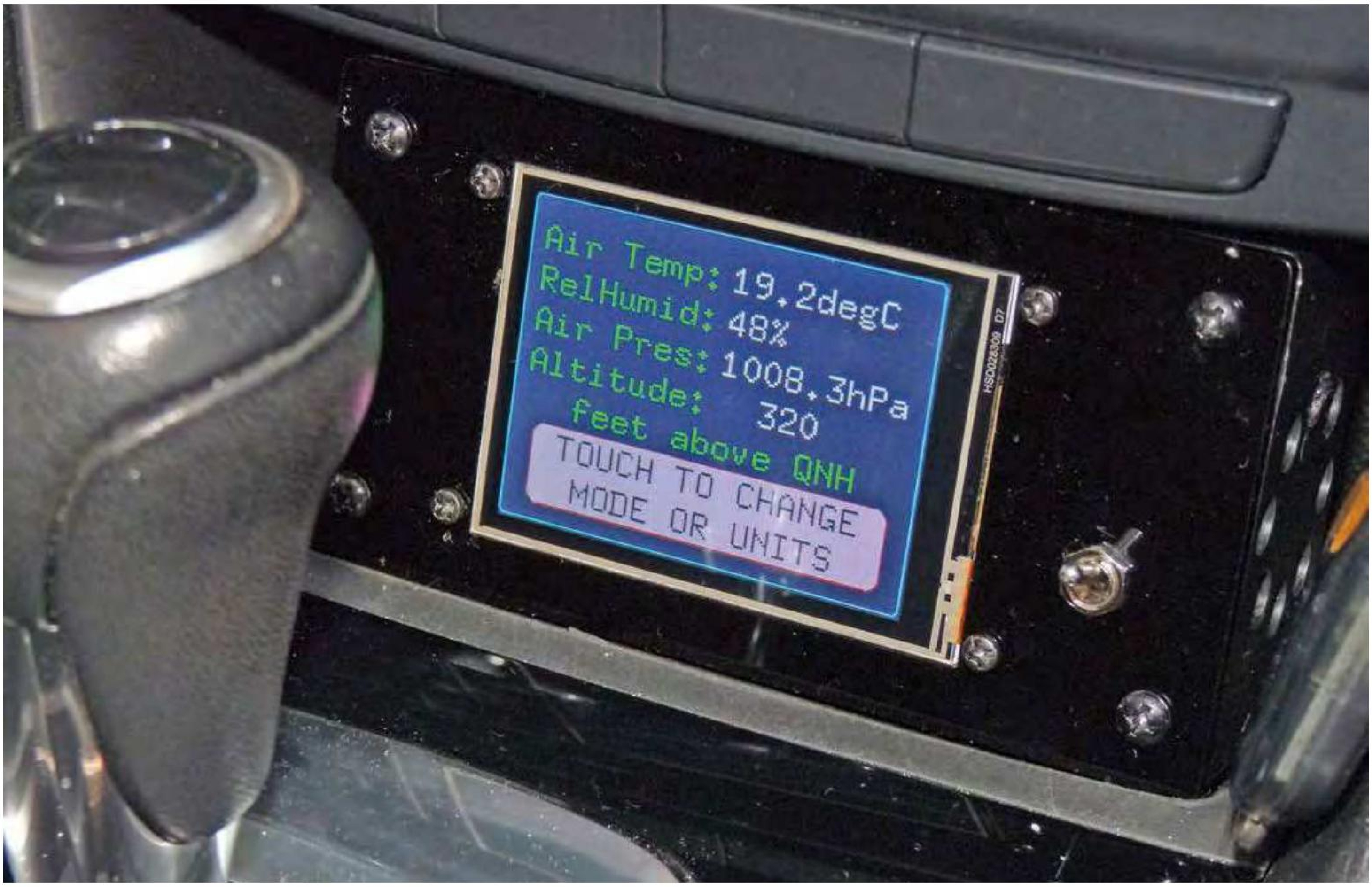
You can buy low-cost pre-built altimeters but they are not very accurate. That's because they typically convert the air pressure reading to altitude with reference to 'Mean Sea Level' (MSL), a fixed reference pressure of 1013.25hPa. But sea level pressure does of course vary (in extreme weather from 870hPa to 1084.8hPa, an error range of 1770m/5800ft).

In reality, we seldom see the extremes, but you can see that basing an altitude reading on MSL will often lead to significant altitude errors.

To solve this, I modified the *Touchscreen Altimeter* software so that you can set the local altitude, such as at your driveway or a lookout (it's usually given), to give a very accurate reference pressure, called your local 'QNH'.

The original *Touchscreen Altimeter* software stored the QNH setting when you turned it off, and loaded it again at startup.

If you drive to a pretty spot for a picnic and shut the *Car Altimeter* down, it will restore with the same



Here's the *Car Altimeter* built into the standard (DIN) dash cutout in my car. It's a large screen, and very easy to read. As the screen says, you can change both the mode and units (eg, feet above sea level, as seen here [which is used in aviation] to metres above sea level, which we're all familiar with). Incidentally, QNH means the atmospheric pressure adjusted to mean sea level. It is neither constant nor the same for various locations – you can get the QNH from weather services.

QNH and preferences when you power up to depart.

But if you stayed overnight, the QNH will probably be significantly different when you set off in the morning, leading to errors that accumulate with each stop.

To solve this, the *Car Altimeter* software records the ground altitude when you power down and uses this value to compute the new QNH on power-up.

The assumption is that the vehicle does not change altitude while you are not driving it (hopefully, a safe assumption!). So the unit should remain accurate for a whole trip, as long as you set its altitude correctly at the start.

This saves you from having to frequently check the current QNH at your location (via the Internet, for example) and update the unit to maintain accuracy.

The *Car Altimeter* is sized to fit into a typical car console pocket (eg, it fits nicely in the console of a Mazda 6). The pocket has an accessories outlet which is hidden, along with the USB adaptor, to the left of the *Car Altimeter*.

Circuit changes

The modified *Car Altimeter* circuit is shown in Fig.1. In addition to the Micromite LCD BackPack, DHT22 temperature/humidity sensor and BMP180 temperature/pressure sensor retained from the previous design, the following elements have been added: a fan with PWM speed control, a small Li-ion battery and a relay driven by a MOSFET plus several diodes.

The PWM control circuity for the cooling fan is provided to keep its noise to a minimum, as small cooling fans are notoriously noisy. This is based on a standard NPN transistor (Q1) driven from Micromite pin 24 via a 2.7kΩ resistor. Schottky diode D5 prevents back-EMF spikes from the fan damaging Q1.

The software uses a PWM frequency of 20Hz with a 50% duty cycle. This gives adequate airflow with minimal noise.

So that the unit can save the altitude at power down, we need to monitor the 5V supply and detect when it starts to drop. Since it drops too fast to give the software enough time to save its settings, rechargeable lithium-ion button cell BAT1 powers the circuit while the 5V rail collapses.

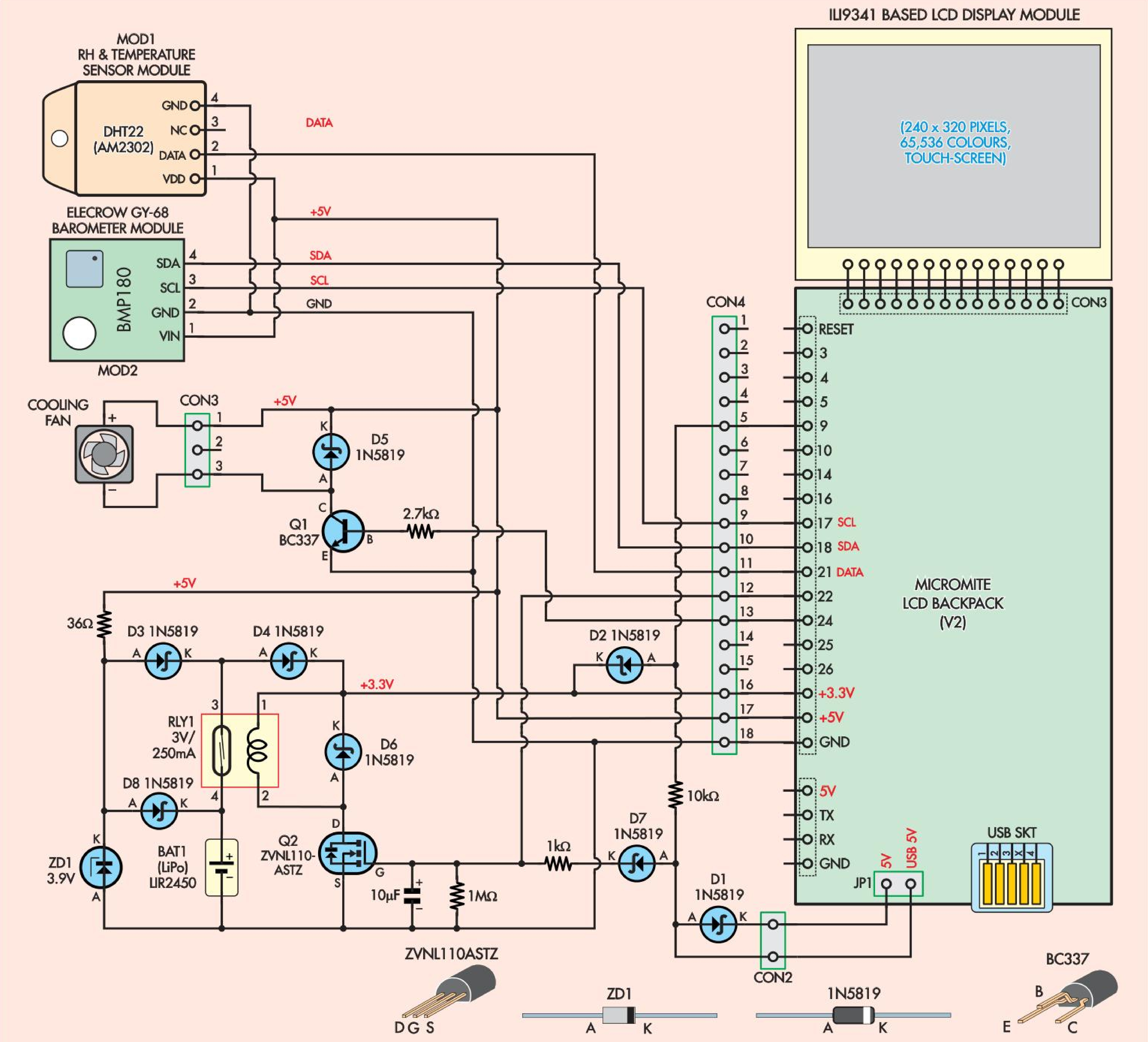
When we have finished storing the data, we switch off the battery supply.

There is another benefit of this battery. The effect of the starter motor on the electrical system of a vehicle can be severe, and the 5V supply can fluctuate enough to upset the *Car Altimeter*. By diode-isolating the 5V rail from the USB input, and using the lithium-ion battery to provide a stable 3.3V supply, we get a reliable boot-up.

Jumper JP1 is used as a connector to access the 5V supply from the USB socket and to feed 5V back into the BackPack, which flows between these pins via schottky diode D1. The USB +5V also goes to the gate of MOSFET Q1 via another schottky diode (D7) and a 1kΩ resistor. This ensures that Q2 switches on as soon as USB power is available, and it powers the coil of relay RLY1.

When the 3.3V rail is derived from battery BAT1, the 5V rail sits at 3.3V; it is backfed through the 3.3V regulator on the BackPack board, from its output to its input via an internal protection diode. D1 prevents this 3.3V from being backfed into the 5V USB source.

RLY1 connects BAT1 into the circuit when MOSFET Q2 is on. BAT1 is charged from the 5V rail via a 36Ω current-limiting resistor and schottky diode D3. Zener diode ZD1 limits the voltage applied to the battery to a safe level for charging (around 3.6V, taking into account the forward voltage of D3).



ILI9341 BASED LCD DISPLAY MODULE
(240 x 320 PIXELS, 65,536 COLOURS, TOUCH-SCREEN)
CON3
MOD1
RH & TEMPERATURE SENSOR MODULE
DHT22 (AM2302)
GND
NC
DATA
VDD
DATA
+5V
SDA
SCL
GND
ELECROW GY-68 BAROMETER MODULE
BMP180
SDA
SCL
GND
VIN
MOD2
CON4
RESET
3
4
5
9
10
14
16
17 SCL
18 SDA
21 DATA
22
24
25
26
+3.3V
+5V
GND
MICROMITE LCD BACKPACK (V2)
5V
TX
RX
GND
5V
USB 5V
JP1
USB SKT
COOLING FAN
CON3
+5V
D5 1N5819
Q1 BC337
2.7kΩ
36Ω
D3 1N5819
D4 1N5819
D2 1N5819
+3.3V
RLY1 3V/ 250mA
D6 1N5819
D8 1N5819
ZD1 3.9V
BAT1 (LiPo) LIR2450
Q2 ZVNL110-ASTZ
10μF
1MΩ
1kΩ
D7 1N5819
10kΩ
D1 1N5819
CON2
ZVNL110ASTZ
D G S
ZD1
A K
1N5819
A K
BC337
B
E C

Fig.1: the *Car Altimeter* circuit is based on that of the *Touchscreen Altimeter*, but it has been optimised for use in land-based vehicles. This includes the addition of a small PWM-controlled fan to ensure the sensors see fresh air, and a backup battery (BAT1) switched by RLY1 to provide power for a brief time after switch-off, so that the current altitude can be saved into flash memory.

BAT1, in turn, powers the +3.3V rail of the BackPack via schottky diode D4. The voltage drop across D4 reduces the 3.6V from the battery to the 3.3V needed. This rail mainly runs the PIC32 micro on the BackPack, which has a recommended maximum of 3.6V and an absolute maximum rating of 4.0V.

Micromite pin 9 is used to sense the 5V USB voltage via a 10kΩ resistor, to determine when the external 5V supply switches off, and Micromite pin 22 is pulled low to forcibly bring the gate of Q2 low, switching RLY1 off and powering down the circuit.

One thing not shown on the circuit is that I added a front panel LCD backlight dimming switch to the BackPack. This connects across the BackPack's onboard brightness adjustment trimpot (VR1), shorting it out when the switch is closed and thus selecting between two different brightness levels: that set by VR1, and full brightness.

This is important so that you can switch the backlight to low brightness at night, to avoid ruining your night vision.

Software changes

The software has been changed in a few places, and some of the changes have been described above. Some improvements have also been made to the user interface.

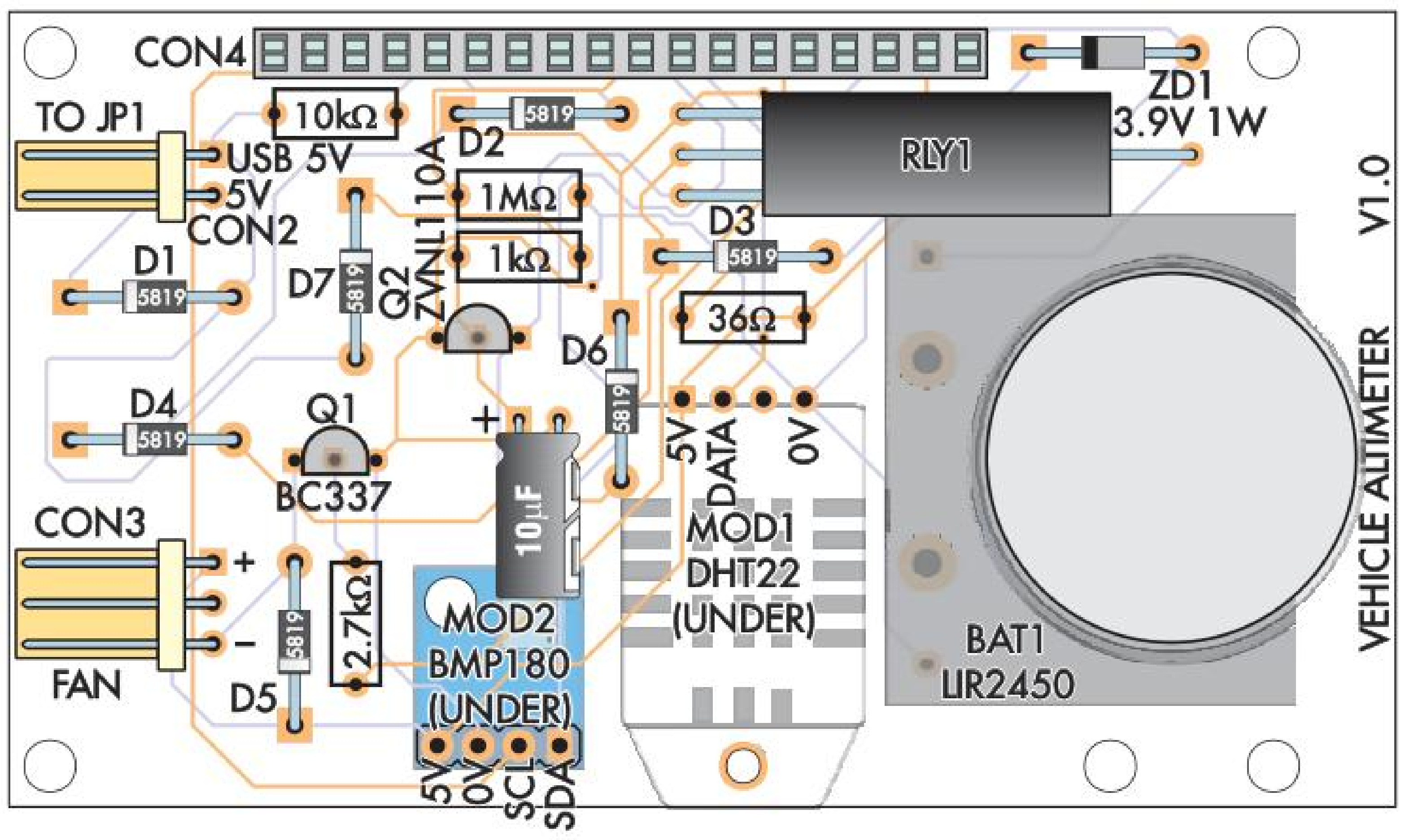
The weather station and altimeter screens are similar to the original. They show altitude above MSL until the QNH or exact altitude has been entered. After that, they show altitude above QNH (Screen 1 and Screen 2).

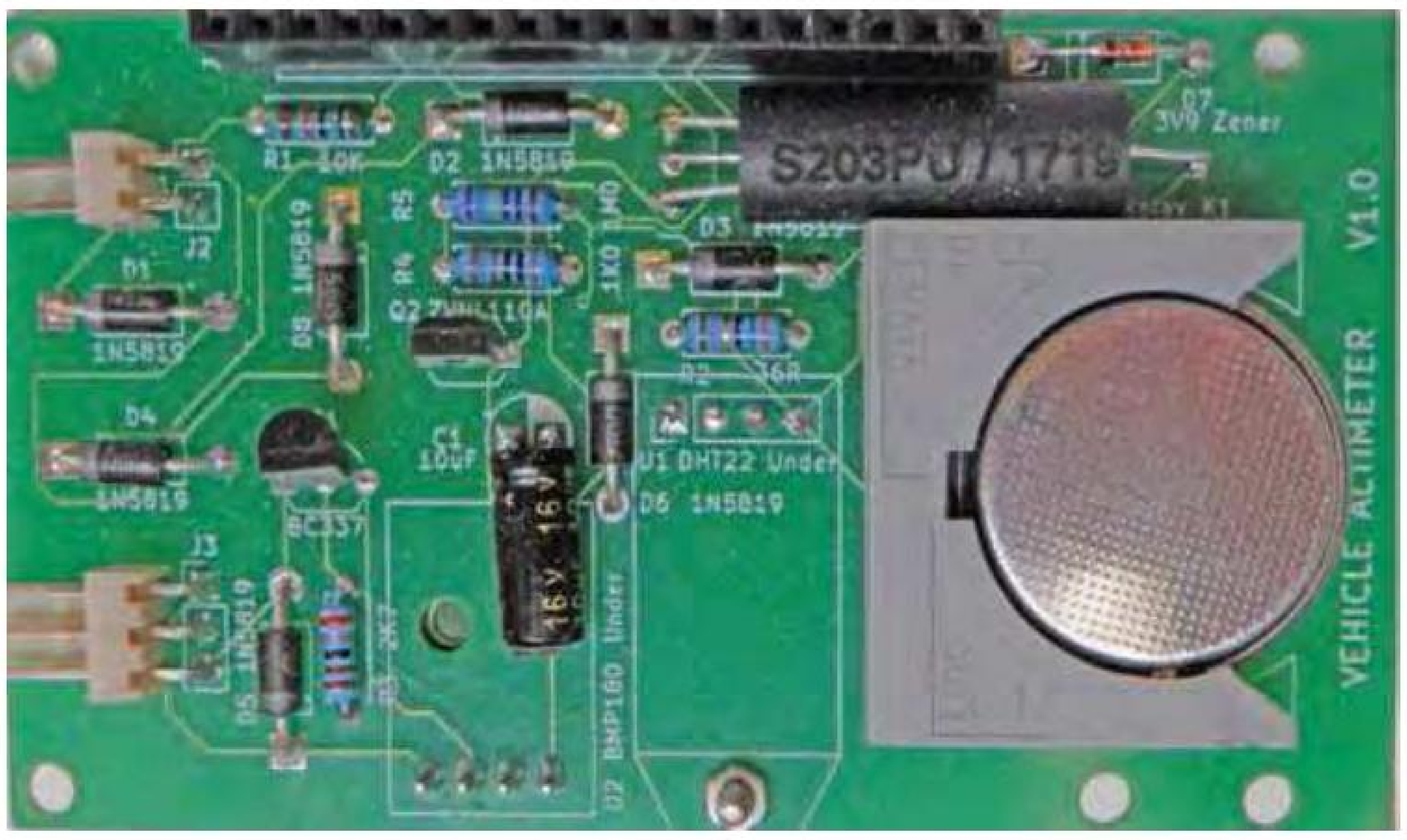
The Change Mode screen has new selections that differentiate between the entry of QNH and the current altitude (see Screen 3). The current QNH value is also shown while you enter either current altitude or QNH (see Screen 4).

If you want to change the fan PWM frequency or duty cycle, search the BASIC code for the line starting with PWM and change the values of 20 (Hz) or 50 (percent duty cycle) to suit.

Power supply

This *Car Altimeter* draws about 90mA at 5V. It can be powered from a low-cost USB power bank (such as Jaycar Cat MB3792), providing run times in excess of 24 hours between charges, making this version practical for use outside of a motor vehicle.


CON4
TO JP1
10kΩ
5819
D2
USB 5V
5V
CON2
1MΩ
1kΩ
ZD1
3.9V 1W
RLY1
V1.0
D3
D1
5819
D7
Q2
ZVNL110A
36Ω
D6
D4
Q1
BC337
+
10µF
5V
DATA
0V
CON3
+
–
FAN
D5
2.7kΩ
MOD2
BMP180
(UNDER)
MOD1
DHT22
(UNDER)
BAT1
LIR2450
VEHICLE ALTIMETER
5V
0V
SCL
SDA



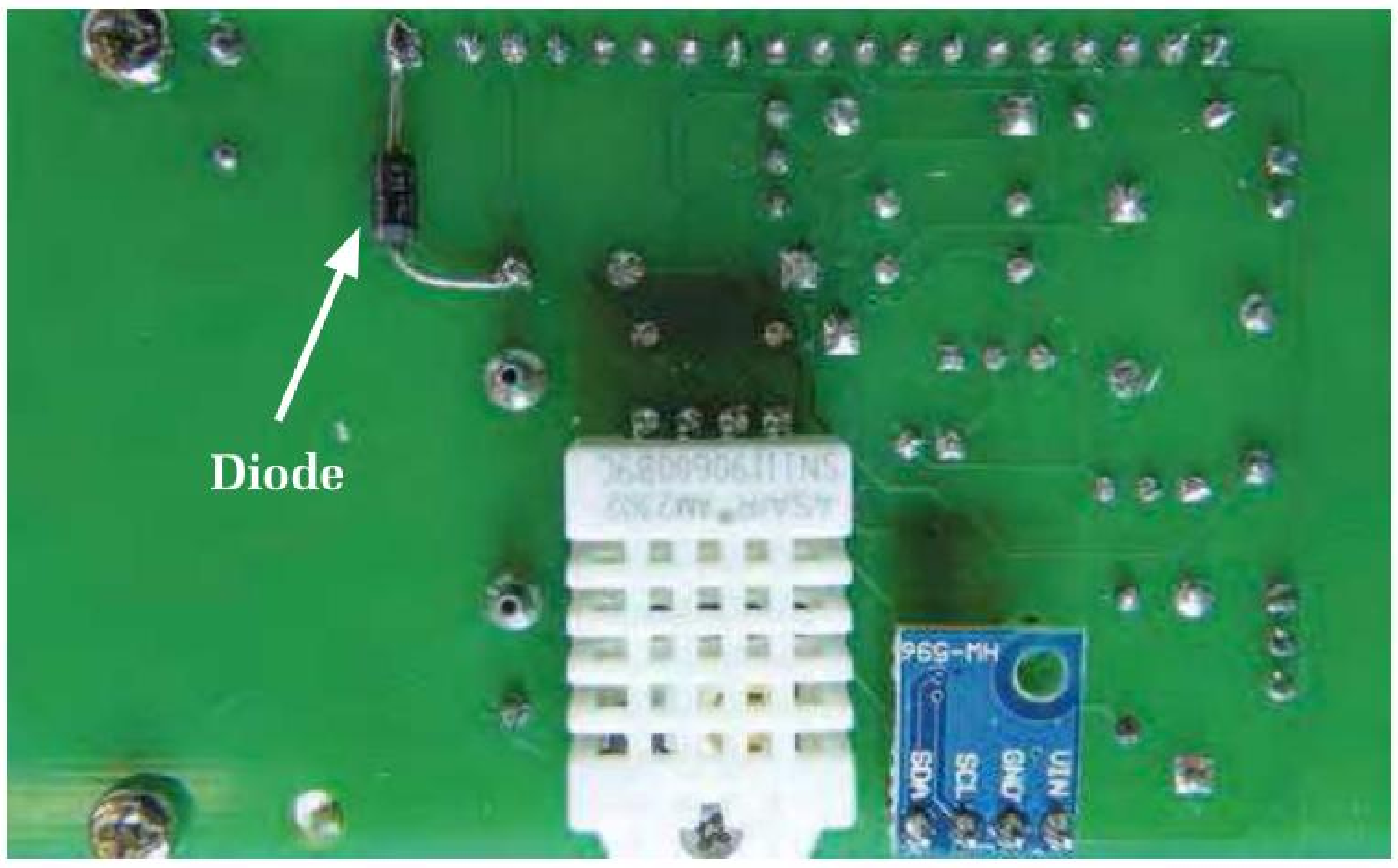


Fig.2: to make assembly easy, all the components which are not part of the Micromite LCD BackPack mount on this similarly sized PCB, with matching front and back photos at right. Only the two sensors are mounted on the back – everything else is mounted on the front of the PCB, including the cylindrical SPST relay (black component top right of upper pic at right) and the rechargeable button cell holder.

Loss of USB power is detected by pin 9 of the Micromite, with a 10kΩ resistor and diode D2 clamping this signal to the 3V3 rail, as Micromite pin 9 is not 5V-tolerant. Power to the Micromite is held on for a short time after the loss of USB power due to the 10µF capacitor at the gate of Q2, which slowly discharges through its parallel 1MΩ resistor. During this time, the Micromite runs from BAT1.

The change in level at Micromite pin 9 triggers a software interrupt that causes the Micromite to store the current altitude data. Micromite pin 22 is then switched low, turning off Q2 and releasing the relay, shutting everything down. Diode D6 suppresses any voltage spike across the relay coil.

In practice, the Micromite runs for about 200ms after a loss of 5V power. This gives the BackPack time to send the message 'Saved' to a terminal attached to the USB cable before the 3.3V supply goes away. You will notice the display dimming briefly as the display backlight runs from 3.3V rather than 5V before it switches off.

Note that the selection of MOSFET Q2 is not critical. Any N-channel enhancement mode MOSFET with a continuous drain current of at least 300mA and a maximum gate-threshold voltage up to 2.0V (typically those designed to be driven from a 3.3V logic supply) should work as well as the ZVNL110A. However, do note that we have not tested any substitutes.

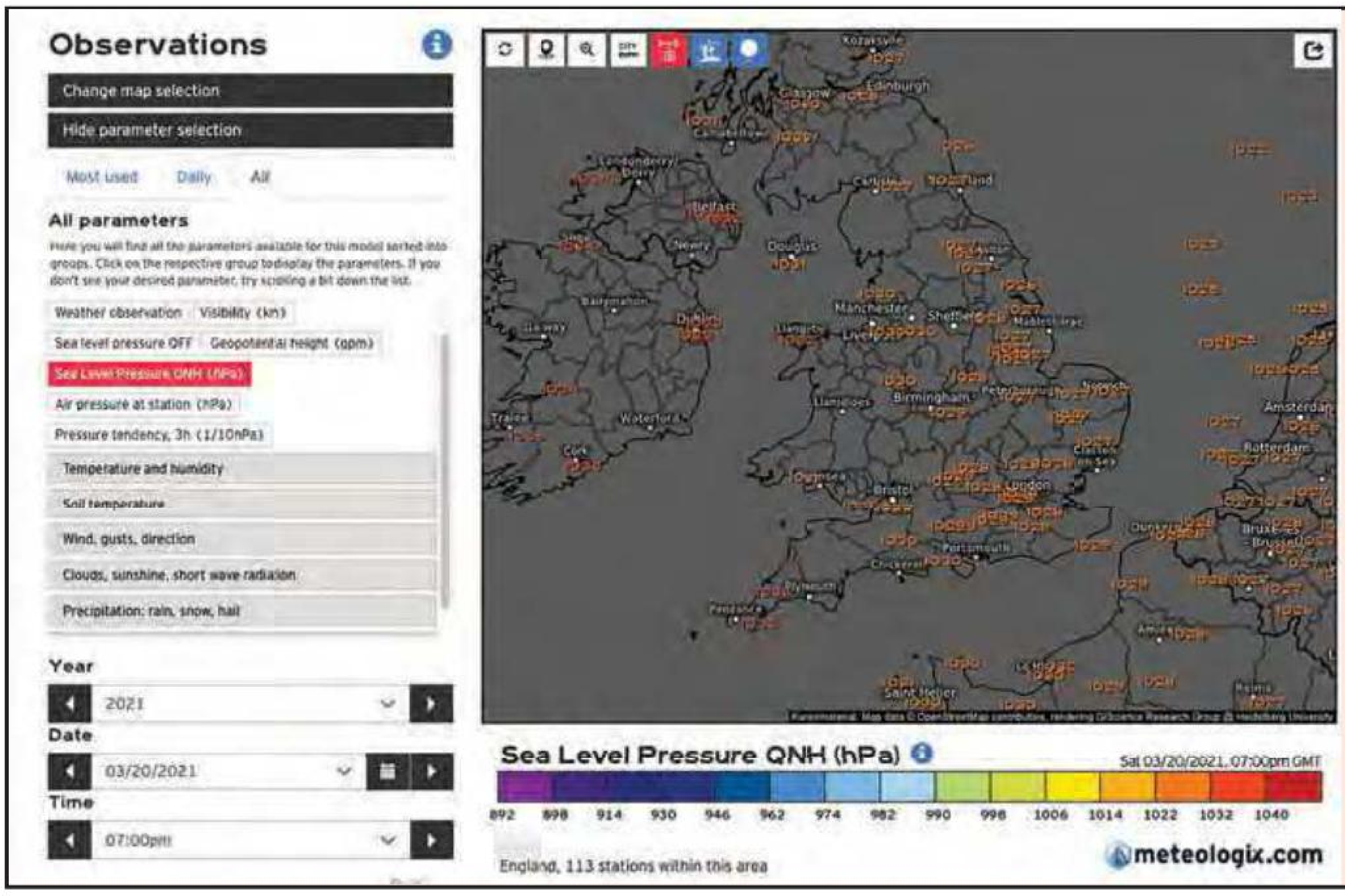
Construction

I have designed a double-sided PCB which holds all the components of the *Car Altimeter*, as shown in Fig.2 and the accompanying photos.

The two sensors (BMP180 and DHT22) mount on the back. This keeps the sensors away from the heat-producing components, in a dedicated cool airstream between an inlet and outlet in the case. This board plugs directly into the LCD BackPack.

Start by begging, borrowing or building the BackPack. We suggest you build V2, although the original will work. We don't recommend using V3 as the *Car Altimeter* software is not designed to accommodate the larger screen, and the inside depth of the V3 box is reduced because of its recessed front panel.

The BackPack V2 construction is fully described in the May 2018 issue of *PE*.


Observations
Change map selection
Hide parameter selection
Most used
Daily
All
All parameters
Weather observation
Visibility (km)
Sea level pressure OFF
Geopotential height (gpm)
Sea Level Pressure QNH (hPa)
Air pressure at station (hPa)
Pressure tendency, 3h (1/10hPa)
Temperature and humidity
Soil temperature
Wind, gusts, direction
Clouds, sunshine, short wave radiation
Precipitation: rain, snow, hail
Year
2021
Date
03/20/2021
Time
07:00pm
Sea Level Pressure QNH (hPa)
Sat 03/20/2021, 07:00pm GMT
892
898
914
930
946
962
974
982
990
998
1006
1014
1022
1032
1040
England, 113 stations within this area
meteologix.com

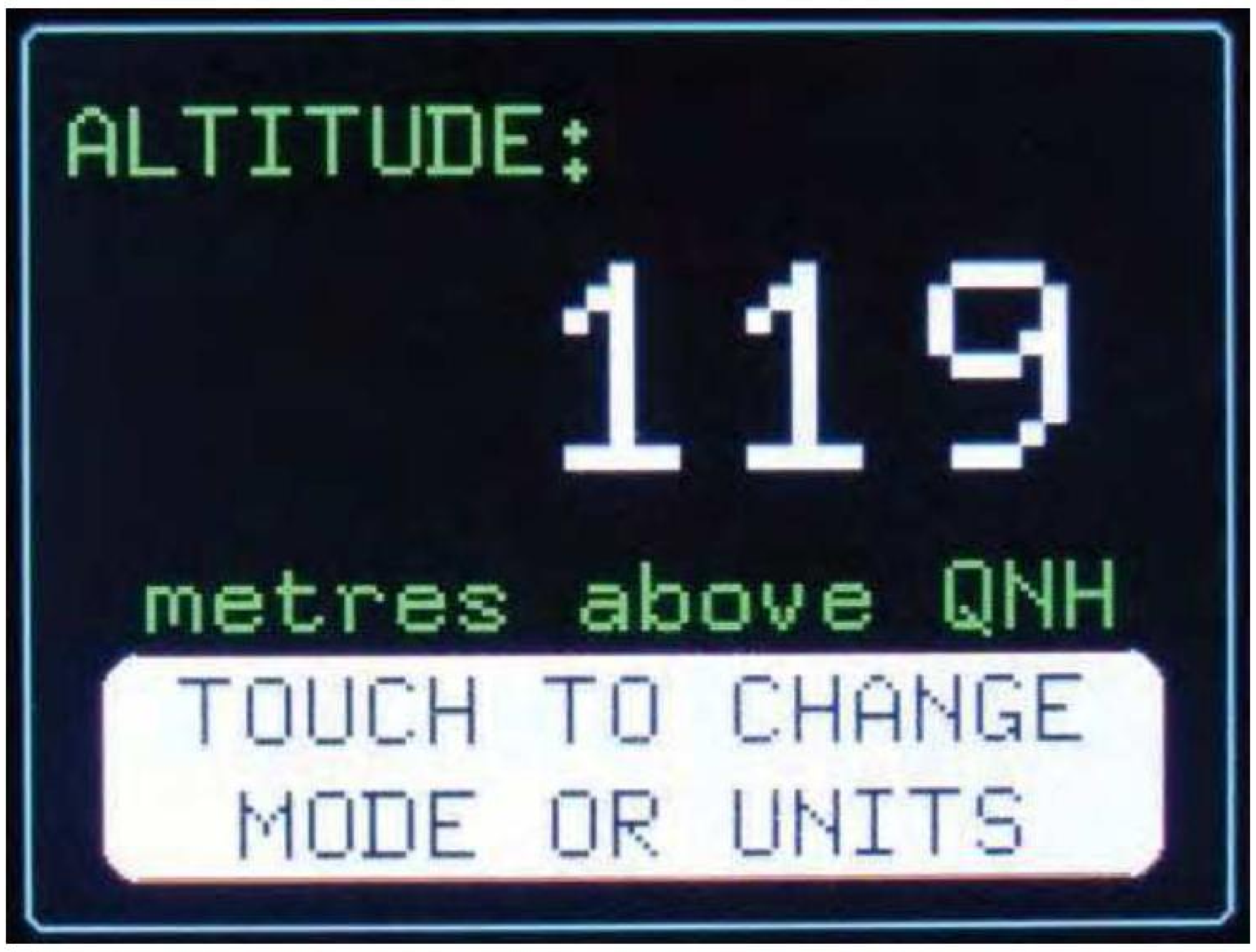
Using Meteologix to get QNH

Meteologix (**https://meteologix.com/uk/observations/pressure-qnh.html**) is a free website for viewing weather forecasts and related information. It also provides QNH.

In this example, you can see a view over most of Britain, Ireland and our nearest neighbours across the Channel overlayed with QNH values.

You can zoom in or zoom out to see the whole of Europe from Iceland to Tukey and Western Russia.

Their website is smartphone friendly, so you can easily source you nearest QNH value on the go.



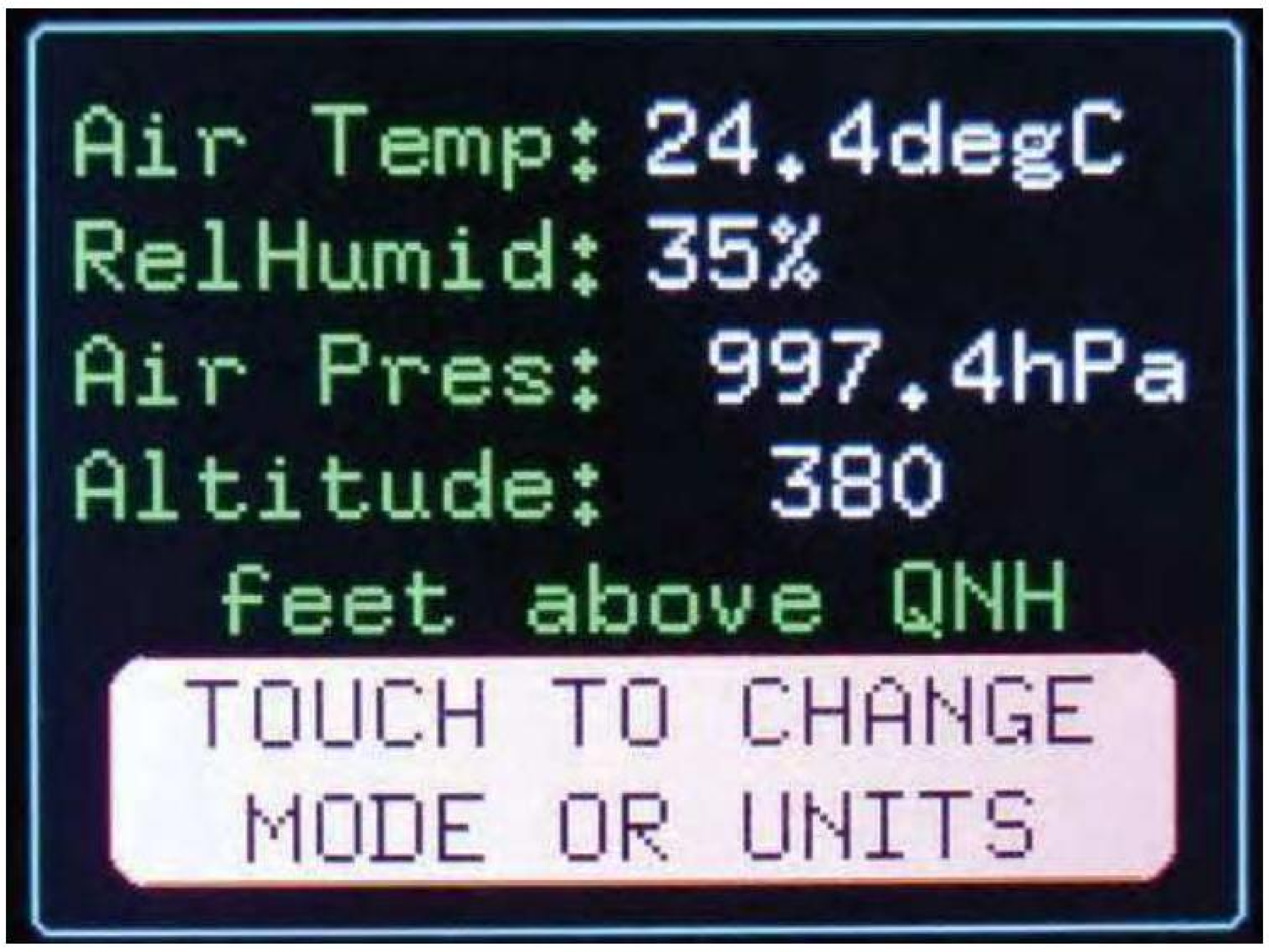
ALTITUDE:

119

metres above QNH

TOUCH TO CHANGE
MODE OR UNITS

Screen 1: the main screen after setting QNH. This shows your altitude above QNH (effectively sea level) in metres or feet.



Air Temp: 24.4degC
RelHumid: 35%
Air Pres: 997.4hPa
Altitude: 380
feet above QNH

TOUCH TO CHANGE
MODE OR UNITS

Screen 2: the extended information screen after setting QNH, showing the altitude in feet along with air temperature, relative humidity and atmospheric pressure readings.

But given its relative simplicity and the fact that the PCB silkscreen shows where the components go, you don't really need to read that article. Simply fit the components where shown on the PCB, and it should work.

Once you've built and tested the BackPack, wire up a toggle switch across trimpot VR1 so that when the switch is closed, VR1 is shorted out and the LCD screen operates at maximum brightness. When it is off, the brightness is set by VR1, which you should adjust to a comfortable level for nighttime viewing.

Note that there are two otherwise identical versions of the 2.8-inch 320×240 LCD touchscreen, one of which uses backlight current control and one which uses voltage control.

If the 100Ω trimpot supplied for VR1 does not adjust the backlight brightness properly, replace it with a 100kΩ potentiometer and wire its unconnected pin to ground. That should do the trick.

Now assemble the interface board by mounting the resistors and diodes on the front side.

Next, add the battery clip, connectors CON2-CON4 and relay RLY1. RLY1 is in a bit of an odd cylindrical package, with three wires at one end and one at the other. Ensure that its type number is facing up and solder it as shown in Fig.2 and the photos.

On the underside, carefully bend the pins of the DHT22 against its body so they pass through the pads.

Attach the sensor with a 2mm screw and solder the terminals, then prepare the BMP180 for mounting by soldering the supplied 4-pin header to its terminals. Secure the assembly to the PCB and solder the header to the PCB respective pads. Check that 'SDA' connects to the square pad.

Now is a good time to solder schottky diode D8 in place on the underside of the PCB, as shown in the photo on p29.

The single capacitor is an electrolytic type which is fitted bent over on its side. Make sure the longer (positive) lead goes to the square pad, marked '+'. Secure the body of the capacitor to the board with a dab of silicone adhesive or a piece of double-sided foam mounting tape. Add MOSFET Q2 and BC337 transistor Q1 where shown, and the board is complete.

Case preparation

Next, prepare the UB3 Jiffy box. The cooling fan mounts on the right-hand end, looking at it from the front (lid), as far towards the back as practical.

Drill four 3mm mounting holes, each at the corner of a 24×24mm square (or mark the positions using the fan), then drill. You then need to drill some holes inside its footprint to allow air through. I suggest eight 6mm holes arranged equally around a 23mm-diameter circle. You can use Fig.3 as a template to mark these holes before drilling.

Drill the same eight air inlet holes on the left-hand end of the case, opposite the fan, but without the fan mounting holes.

Next, locate a convenient point on the back of the box for the USB cable to exit. Drill an 11.5mm-diameter hole to take a cord-grip clamp. We located it 20mm from the fan end (RH), 10mm from the top. This gives enough length to withdraw the electronics from the box.

Drill a hole in the front panel to mount the dimmer switch, ensuring the switch clears both the fan and the BackPack connectors.

Cut the cooling fan leads to about 150mm and attach the 3-pin female socket to match CON3 on the interface board. Then make up the 2-pin cable linking CON2 on the interface board to LK1 on the backpack.

To connect to LK1, cut a two-contact section from the leftover remnant of the strip used to make CON4, fold the pins against the body, solder the wires to the pins and heat shrink the wires to the body. This keeps the connector short enough to fit between the BackPack LK1 and the display.

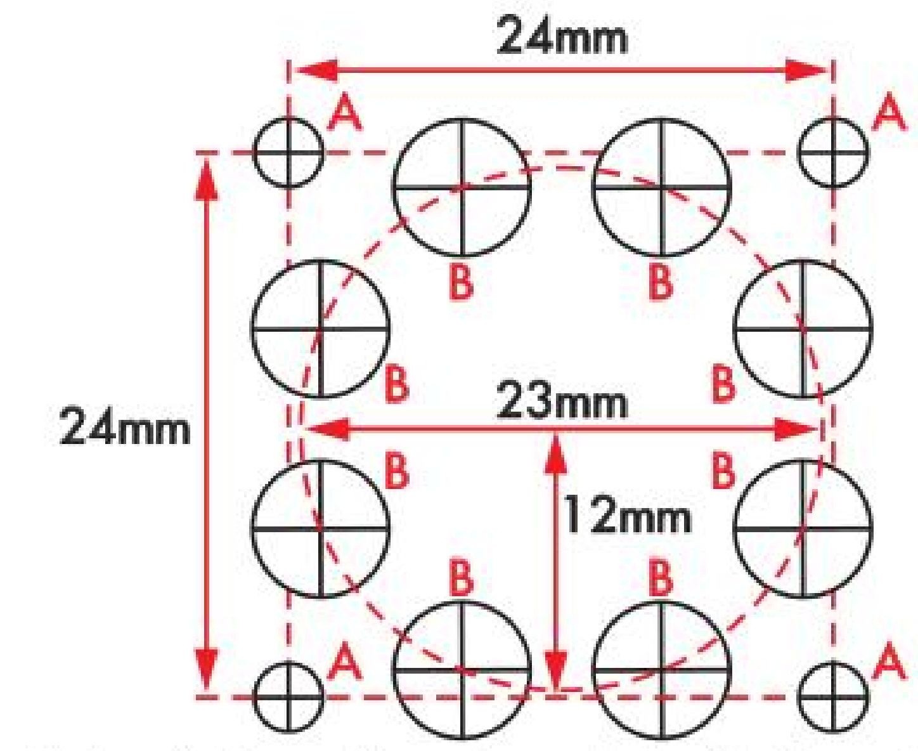
Carefully check the connections. If you swap the wires, diode D1 on the interface board will isolate everything from the 5V input.

The USB cable is a tight fit against the end of the box. We carefully removed some of the plastic reinforcement at the mini connector, and applied gentle heat to persuade the cable to lie in our preferred direction.

The USB mini connector can be inserted through the exit hole in the back of the box and the cable secured with the cord-grip clamp. Insert the LIR2450 battery into its clip, mount the interface board on the BackPack with 12mm untapped spacers and 20mm M3 screws. Construction is now complete.

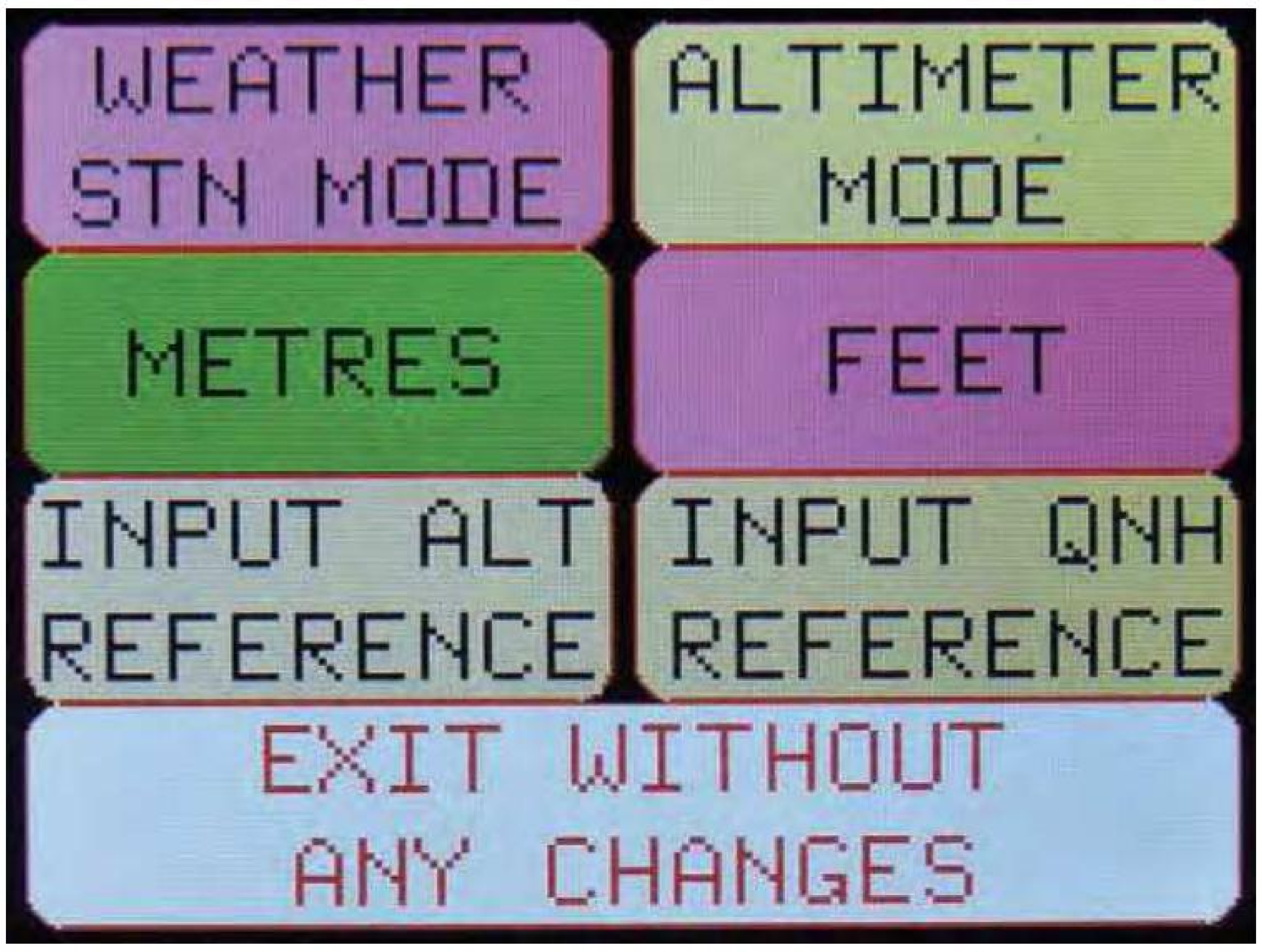
Testing

Load the *revised* altimeter software named **Altimeter with power fail 1_0. bas** (available for download from the May 2021 page of the *PE* website) into the Micromite and run it. The first time it is run, the display should initialise

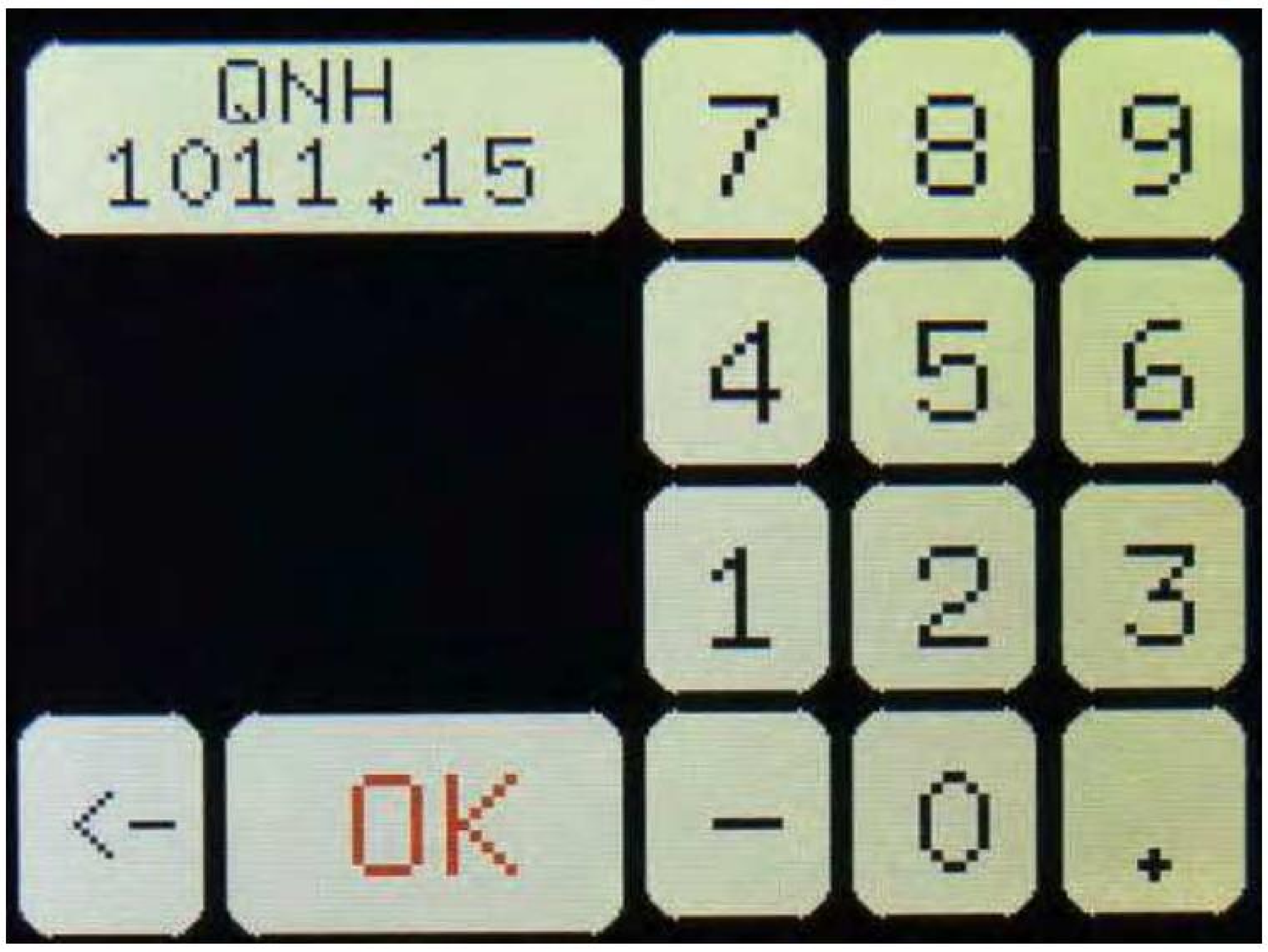


Holes A: 3mm diameter Holes B: 6mm diameter
Note: Holes A are only drilled on one side of the case

Fig.3: use this diagram as a guide or template to drill the eight airflow holes at both ends of the case, plus the four mounting holes for the fan at the right-hand end.



Screen 3: the settings screen has two buttons at the bottom for calibration; one for entering the currently known QNH value, and one for entering your current altitude in feet.



QNH
1011.15

Screen 4: the current value of QNH is shown as you are typing in the new one. This reminds you which value you are updating.

with the weather station screen using MSL as the reference.

Connect the *Car Altimeter* to a terminal such as Teraterm or MMEdit. The LED on the BackPack should flash twice per second as the Micromite sends the message 'pass' to the terminal. If the *Car Altimeter* fails to start, check the connection from CON2 to LK1. The cooling fan should run if the software has initialised.

Check that the battery is charging. It should be approaching 3.6V. The voltage drop across the 36Ω resistor should be about 0.9-1.1V when the battery is charged. You can probe this on the reverse side of the board.

Check the touchscreen selections for correct function. To find the QNH to enter, the best method is to use a website such as **Meteologix.com** (see panel). Use the map to find your nearest QNH value. Even if it's not exactly your location it will be a very similar pressure value.

When you make a change such as entering QNH or Alt reference (current known altitude), you may notice the altitude reading converging on the final value over five seconds. This is because this software version averages the readings to eliminate short-term fluctuations and improve the accuracy of the saved altitude at power down.

With a terminal connected and monitoring the USB signal, the terminal should show 'pass' once per second. Disconnect the cable from CON2. The terminal should display the message 'saved', indicating that the current altitude has been saved.

Assemble the front panel to the box. You may have to source longer self-tapping screws than those provided, or you can tap the mounting bosses and use machine screws.

Your *Car Altimeter* should now be ready for use.

Precision, accuracy and errors

Remember that a pressure altimeter is not an instrument of survey accuracy. Even if it can display altitude to a precision of one foot, it is likely to be displaying the wrong altitude very precisely because it is subject to several variables.

One such variable is QNH drift. Official meteorology bodies are continually amending QNH, and pilots must continually correct their altimeters. Also, the QNH derived from **Meteologix.com** is truncated to the unit of hPa. Straight away, you have a possible error of ±30ft/10m.

Another error derives from temperature differential. If you park in the sun and turn off the engine, the current altitude will be saved. However, when you return and restart the engine, the car interior temperature could be 20°C higher than ambient. The *Car Altimeter* will use this temperature to calculate the new QNH. This error can be up to 6m/20ft for a 20°C difference.

These errors would be unacceptable for night instrument landings, but are not a big deal for either road travel or recreational aviation. Don't stress. Re-enter the QNH and go and enjoy!

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Parts list – Car/Truck Altimeter

1 assembled Micromite LCD BackPack (V2 preferred – PCBs for this version are now back in stock at the PE PCB Service). In general, for UK readers sourcing Micromite-related parts we recommend using Phil Boyce's online shop at: **micromite.org**
1 DHT22 temperature/humidity sensor (MOD1)
1 GY-68 BMP-180 temperature/pressure sensor module (MOD2)
1 double-sided PCB, coded 05105201, 86.5 x 49.5mm
1 black or grey UB3 Jiffy box [Jaycar HB6013/HB6023]
1 panel-mount SPST/SPDT toggle switch [eg, Jaycar ST0335]
1 thin 30mm 12V DC cooling fan [Jaycar YX2501]
1 3V DC coil, 250mA SPST reed relay (RLY1) [RS Cat 124-5129]
1 PCB-mount 2450 coin cell holder (BAT1) [element14 Cat 1216361]
1 LIR2450 Li-ion rechargeable cell (BAT1) [element14 Cat 2009025]
1 2-pin right-angle polarised header and matching plug (CON2)
1 3-pin right-angle polarised header and matching plug (CON3)
1 18-pin header socket (CON4)
1 50cm+ USB cable [eg, Jaycar WC7709]
1 6.2-7.4mm cordgrip clamp [Jaycar HP0718]
4 12mm-long M3 tapped nylon spacers
4 M3 x 15mm machine screws

Semiconductors
1 BC337 NPN transistor, TO-92 (Q1)
1 ZVNL110ASTZ N-channel MOSFET or similar, TO-92 (Q2) [RS Cat 823-1833]
1 3.9V 1W zener diode (ZD1) [eg, 1N4730]
8 1N5819 1A schottky diodes (D1-D8)

Capacitors
1 10µF 16V electrolytic

Resistors (all 1/4W 1% metal film)
1 1MΩ 1 10kΩ 1 2.7kΩ 1 1kΩ 1 36Ω

DIY SOLDER REFLOW OVEN WITH PID CONTROL

Part 2

by
Phil Prosser

When we left off last month, we'd finished assembling the PCBs and the hardware. Now it's time to put it all together – and get cooking!

Just in case you missed this project's first instalment last month, let's briefly recap. We're taking a bog-standard 'toaster oven' and making a controller for it, which allows it to be turned into a reflow oven for soldering PCBs with lots of (or even a few) SMD components.

We do this without any modifications to the toaster oven at all – in fact, there is only minimal mains wiring to be done within the controller. What's more, we've made it very safe to use.

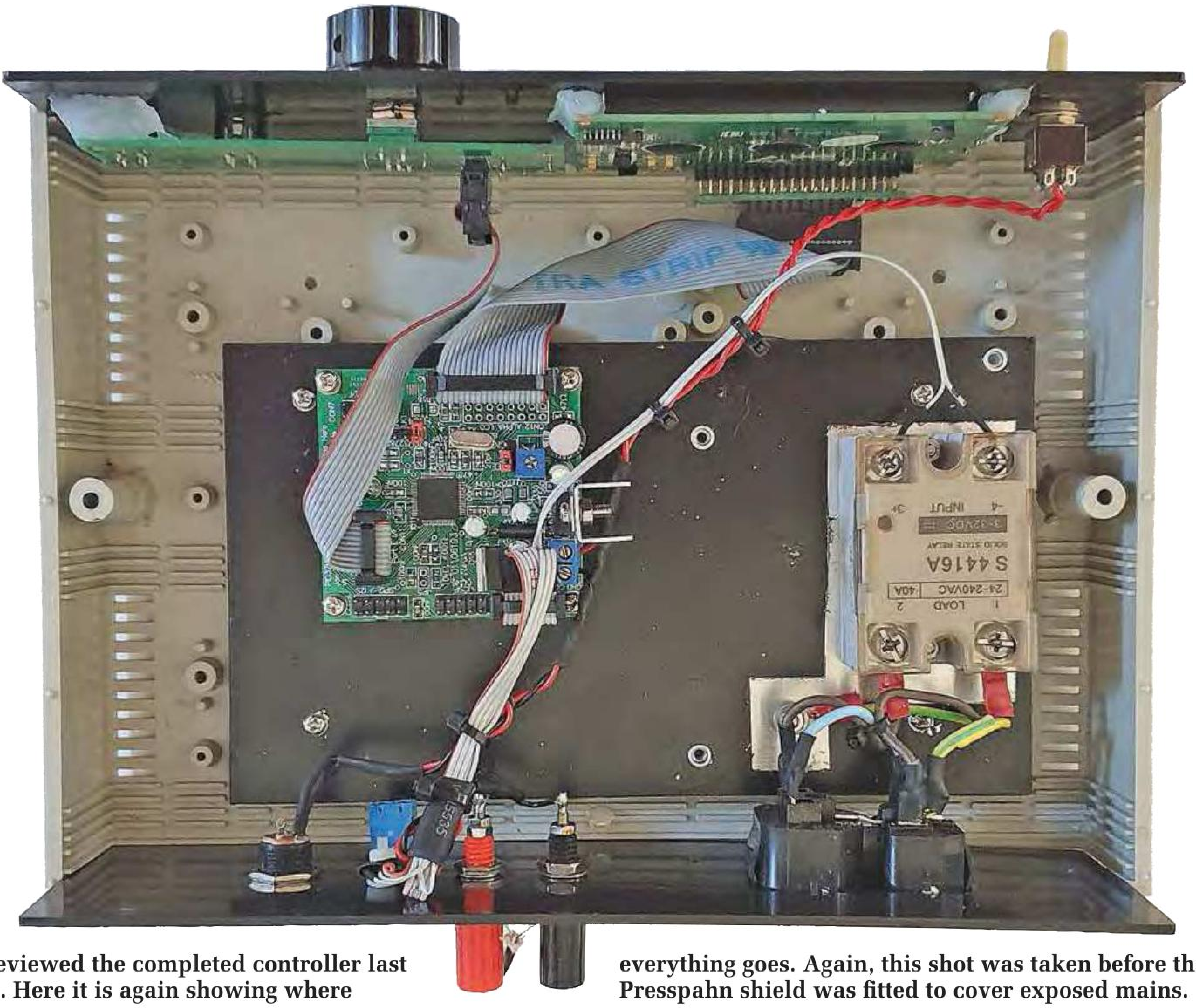
If you want more details than that, we suggest you look up the first part in the April 2021 issue. Now, let's get on with the show!

Putting it together

Everything mounts inside a commercial plastic case, with the components mounted on a baseplate made from 1.5mm-thick aluminium. Cut it to 200 × 115mm and drill all the required holes, as shown in Fig.8. Deburr all the holes and clean it up.

We haven't shown a cutting/drilling diagram for this simply because of its size but we have prepared one; it can be downloaded from the May 2021 page of the *PE* website and printed out at 1:1 size.

Covering the panel with masking tape before cutting out the display window has two benefits: (a) you can much more easily mark the position on the tape (along with other hole locations) and (b) it tends to make the waste stay in place, resulting in less mess!



We previewed the completed controller last month. Here it is again showing where everything goes. Again, this shot was taken before the Presspahn shield was fitted to cover exposed mains.

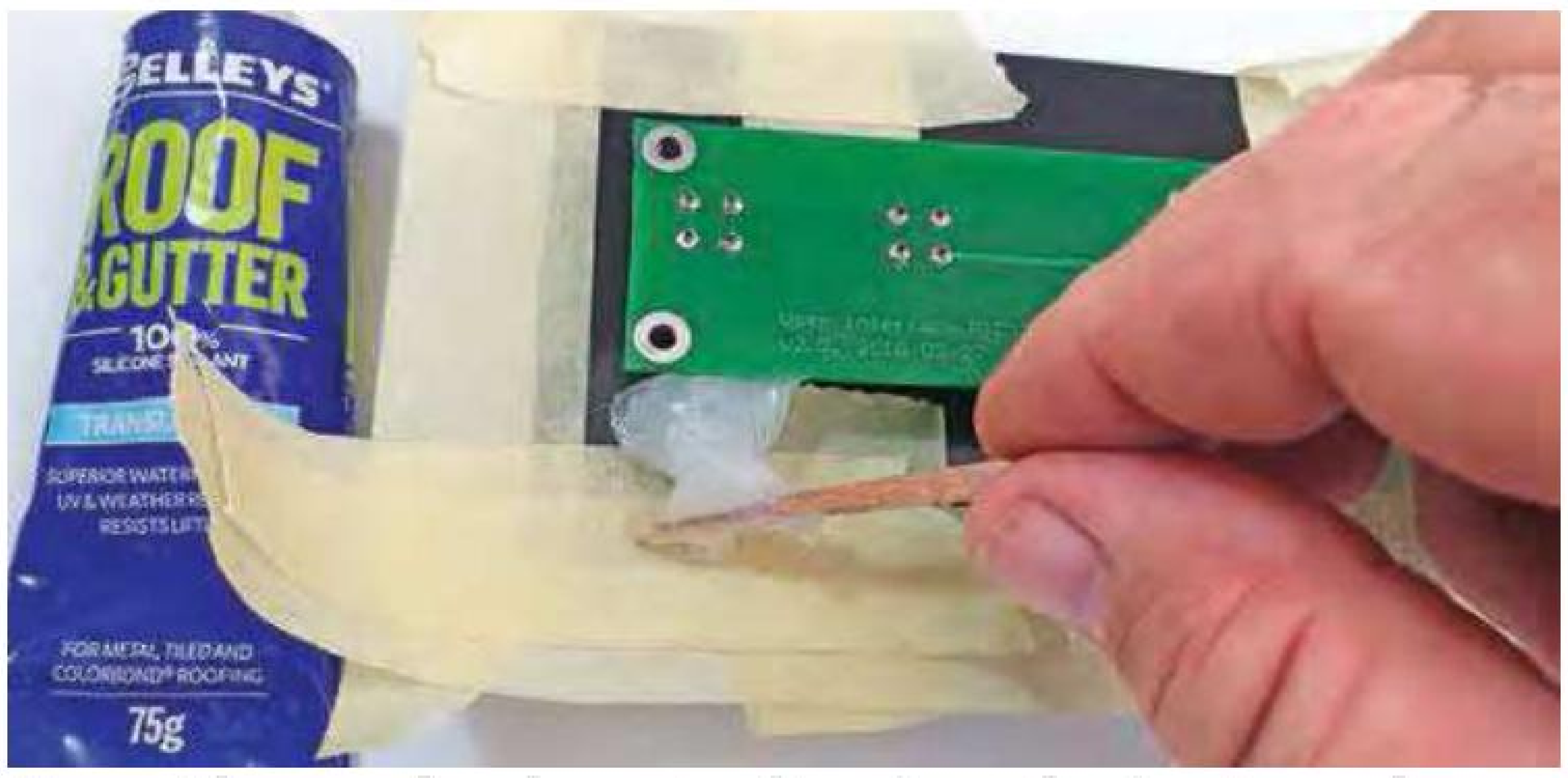
Similarly, drilling diagrams for the front and rear panels, along with a cutting and drilling diagram for the Presspahn safety shield can also be downloaded in a single PDF document. Now would be a good time to get those diagrams and cut/drill the components.

We applied masking tape to the front and rear panels and marked cuts and holes on this. For the LCD and the IEC connector, we used a Dremel with a cut-off wheel to cut just inside the marked cut lines, then used a file to tidy the holes. This gave a neat result.

Use the aluminium plate as a template in the bottom of the case to mark out and drill the holes which will be used to attach the plate to the base.

Be careful to leave a minimum of 40mm of room to the front panel for the LCD connector.

Now you can start to fit the components to the baseplate. Apply a small dollop of heatsink paste under the solid-state relay before mounting it.



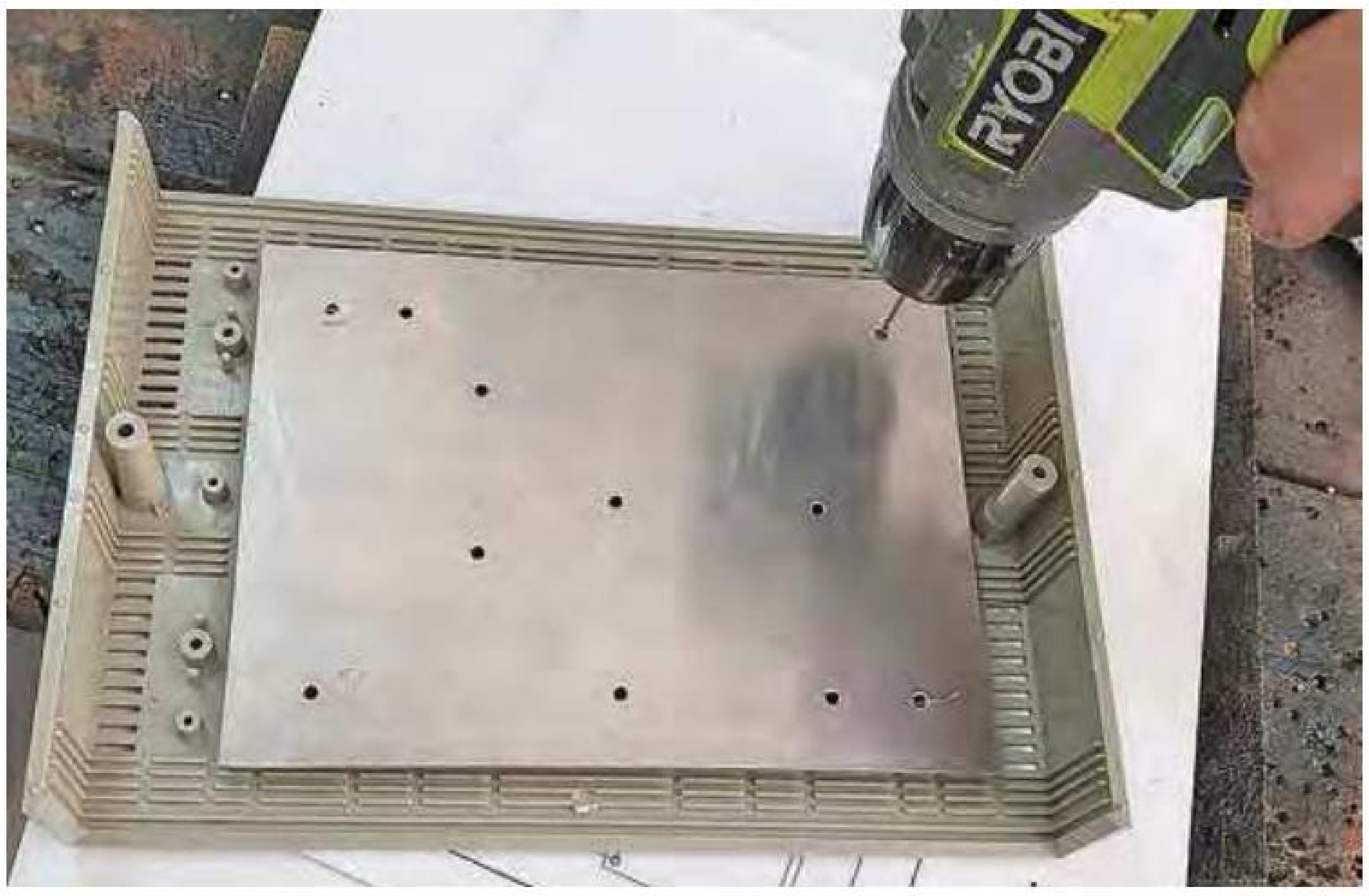
To avoid screw heads protruding from the front panel, we decided to glue the LCD to the rear of the panel using silicone sealant. The masking tape showed us where the glue was to go.

Mount the PIC32MZ PCB using 15mm nylon standoffs. These ensure that the board is well insulated, with sufficient creepage distance from the base plate. Do not substitute metal standoffs. You can then attach the metal plate to the bottom of the instrument case and move on to the front and rear panels.

For the rear panel, attach the dual IEC connector, binding posts and DC socket securely. We can solder wires to these in situ later.

It is now time to mount the LCD screen and front panel PCB. We used glue (actually, silicone sealant) to avoid messy screws through the front panel, and to make it bombproof. You just need to be a bit careful in application. Start with the LCD.

If your cut-out leaves a gap around the LCD screen, you may be able to see the white of the backlight assem-



Once you've drilled out the baseplate (download the PDF from the May 2021 page of the *PE* website) it can be used as a template for drilling the four required holes in the case (these align with four of the pillars moulded into the case).

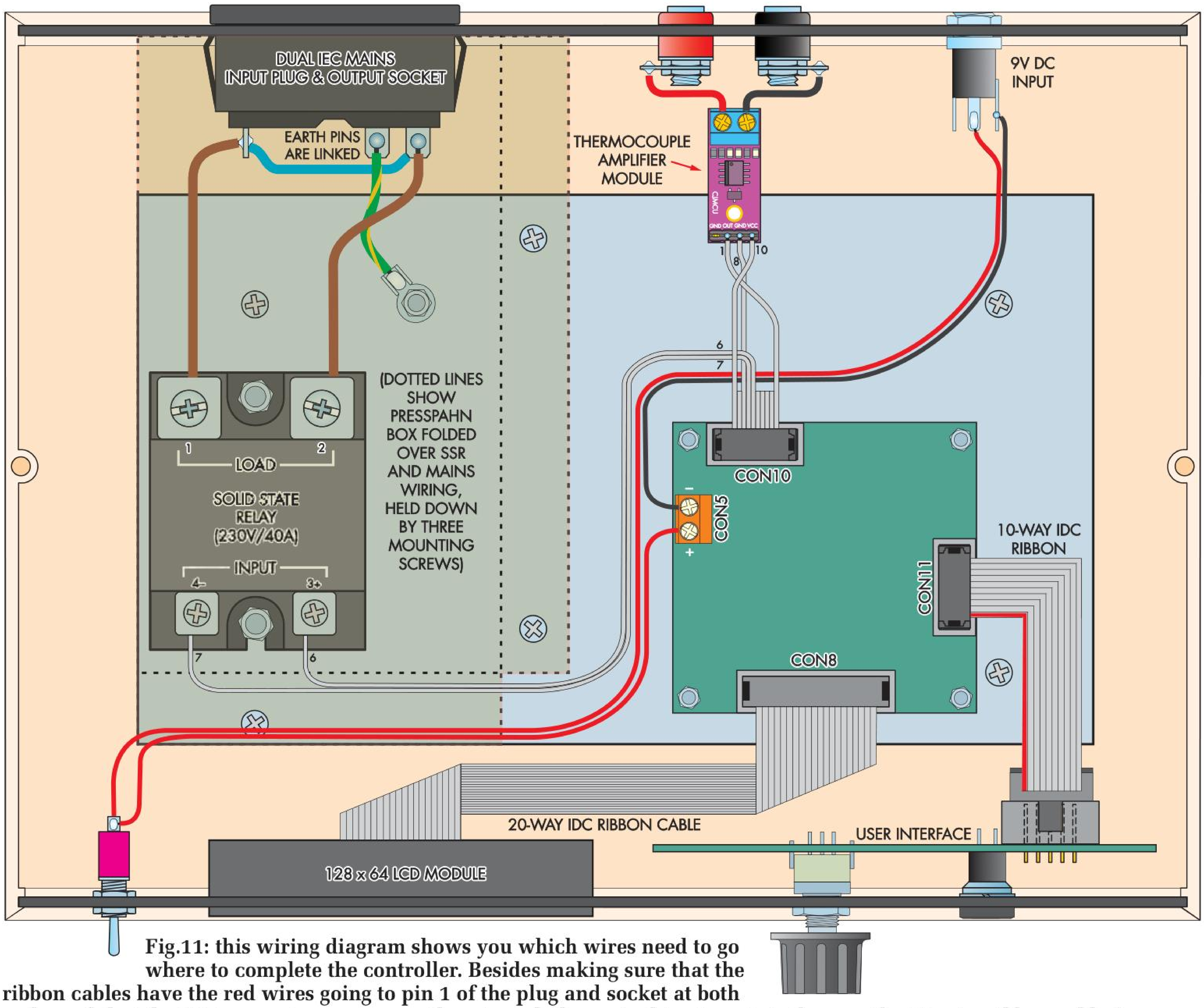

DUAL IEC MAINS INPUT PLUG & OUTPUT SOCKET
EARTH PINS ARE LINKED
THERMOCOUPLE AMPLIFIER MODULE
9V DC INPUT
1
8
10
6
7
(DOTTED LINES SHOW PRESSPAHN BOX FOLDED OVER SSR AND MAINS WIRING, HELD DOWN BY THREE MOUNTING SCREWS)
1
2
LOAD
SOLID STATE RELAY (230V/40A)
INPUT
4–
3+
7
6
CON10
–
CON5
+
10-WAY IDC RIBBON
CON11
CON8
20-WAY IDC RIBBON CABLE
USER INTERFACE
128 x 64 LCD MODULE

Fig.11: this wiring diagram shows you which wires need to go where to complete the controller. Besides making sure that the ribbon cables have the red wires going to pin 1 of the plug and socket at both ends, and that the IDC connectors are correctly crimped, the main thing to note is the way the 10-wire ribbon cable from CON10 is split up and routed to two places. Only five wires in this cable are used; the other five should be cut short. When finished, use cable ties to tie all the bundles of wires together, so nothing can move around, and don't forget to add the Presspahn barrier.

bly through the gap. Use a black marker to colour in the white backlight around the edges of the LCD panel before mounting it.

Put masking tape across the front panel cut-out and temporarily mount the LCD, making sure that the connectors are on the bottom. The tape should hold the LCD pretty well flush with the front panel.

Also, apply masking tape around the LCD edges to facilitate tidying up the silicone after you have applied it. Refer to the accompanying photo.

Next, attach the front panel control board. Put one nut (or several washers) over the rotary encoder shaft to set a minimum depth, then mount it to the front panel using the supplied nut. Check the pushbuttons operate properly and do not get stuck on the front panel. If they do, carefully file the holes a bit larger with a round file.

Once it is all good, tighten up the nut on the rotary encoder and check that everything is sitting neatly. Adjust if necessary.

Then, using a matchstick or small timber offcut, build up a dollop of silicone at either corner of the LCD. Do the same with the control board, at the end far from the rotary encoder. Watch out for the pushbutton; do not get silicone onto this, or it will stop it working. You do not need to use a lot of silicone – a 'dollop' at either corner is more than enough. (We used far more than necessary!)

Once the silicone has set, attach the on/off toggle switch in the usual manner, and push a knob onto the rotary encoder. You are now ready to start the wiring.

Wiring it up

Fig.11 shows the wiring that's needed to finish the controller. As you do the wiring, keep in mind that twisting pairs or bundles of wires together and/or covering them in heatshrink tubing will keep the whole thing neat.

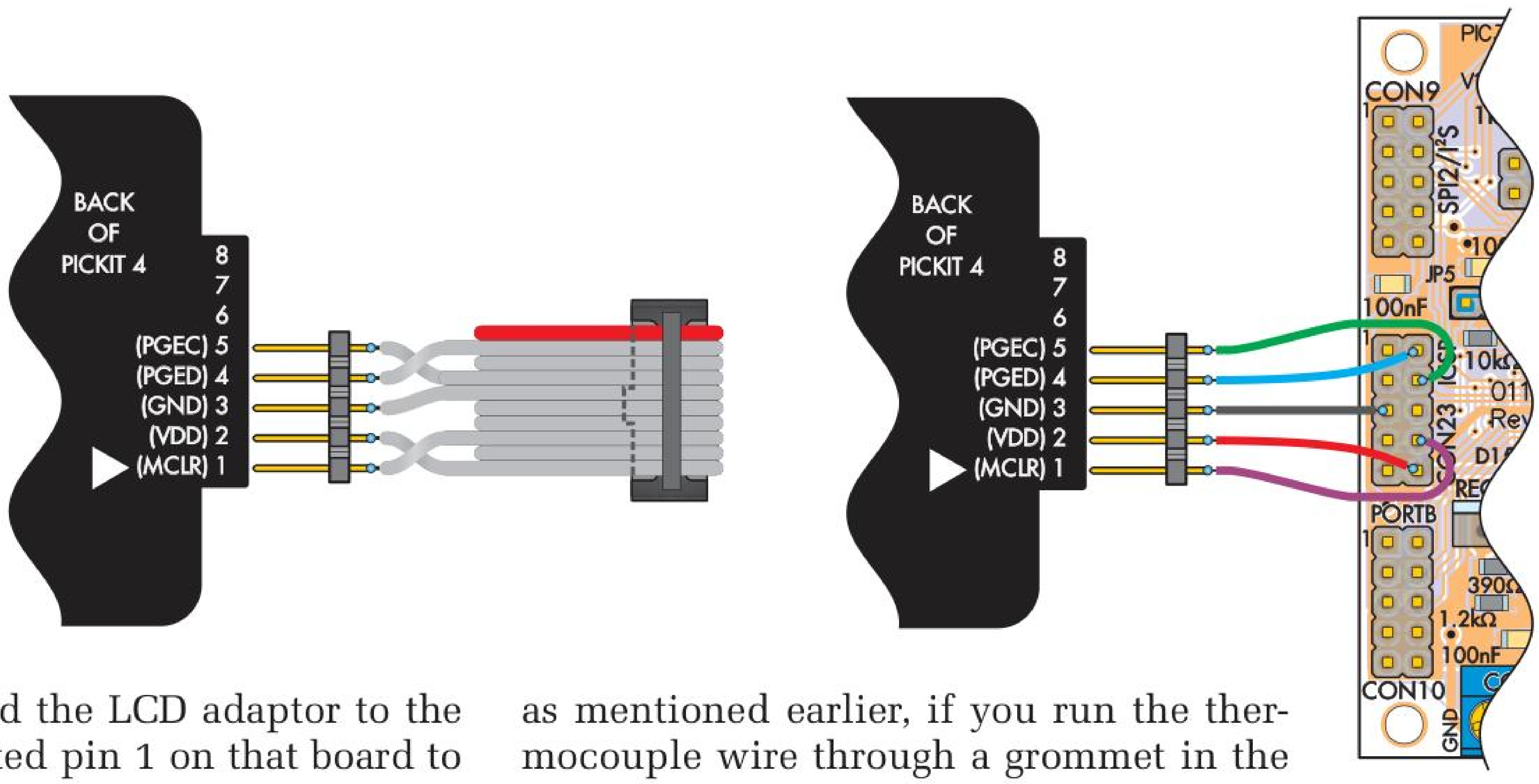
It's important to note that this also contributes to safety, as it stops wires that might break off from moving around and contacting other parts of the circuit. See our photos for an idea of what it should look like when you've finished.

Start by running light-duty red hookup wire from the middle pin of the barrel connector to the front panel on/off switch, then from the other terminal of the on/off switch to the + power input of the PIC32MZ controller board. Run light-duty black wire from the DC socket ground (outer connector, as shown in the photo) to the PIC32MZ's GND power input.

Twist these together and use heatshrink to make the connections tidy. Then plug in the two ribbon cables you made earlier, one from the CON11 on the CPU board to CON2 on the front panel, and the other from CON8 on the CPU board to the DIL header on the back of the LCD adaptor board. In each case, make sure the red stripe side of the cable goes towards the pin 1 side on the connector.

Fig.12: When programming a blank PIC32 or there is a firmware update, this is how to connect a PICkit 3/4 or similar to the board to reflash the chip.

The code for programing is available in the download package from the May 2021 page of the *PE* website.



Hopefully, when you soldered the LCD adaptor to the LCD screen earlier, you connected pin 1 on that board to pin 1 on the LCD. If not, rotate the IDC connector plugging into the LCD adaptor by 180° to compensate.

The specified dual male and female IEC connector allows a conventional IEC mains power cord to supply power to the unit, and also makes it easy to connect up to the oven.

Strip out a length of 10A mains flex or an unused 10A-rated mains power cord to get the brown, light blue and green/yellow striped wire that you will need to wire this up to the SSR.

For the following mains wiring, keep all the wires as short as possible to maximise safety (the earth wire is less critical, but it's still better to keep it short if possible.)

Use a short length of the light blue wire to join the two neutral connectors on the socket together. These are both marked with an 'N'. Then crimp an eyelet lug onto one end of a short length of green/yellow striped wire, solder the free end to the earth connector on the mains socket and attach the eyelet to the baseplate using a machine screw, a shakeproof washer (under the eyelet) and two nuts.

Cut two lengths of brown wire and crimp eyelets to one end of each, then solder the free ends to the incoming and outgoing Live terminals on the mains connectors. It doesn't matter which wire goes to which load terminal on the SSR - this is AC after all, so current must be able to flow in both directions.

Note that you could connect to the SSR using bare wires rather than eyelet lugs, but we feel that using a crimped connector makes it a bit tidier. Just make sure they are securely crimped. Apply insulation to all of these connections, and double-check them, then cable tie them all together, so that if one comes loose, it can't go anywhere.

Thermocouple input wiring

The two binding posts are mounted 20mm apart, allowing the Jaycar QM1284 thermocouple to be plugged straight in. This provides a professional-looking solution. However, as mentioned earlier, if you run the thermocouple wire through a grommet in the rear panel and connect them directly to the screw connectors on the thermocouple amplifier board, the temperature readings will be more accurate.

The downside is that you now have a captive thermocouple wire, so changing the thermocouple is a tedious job.

The thermocouple and also the solid-state relay signals connect to CON10 (PORTB) on the PIC32MZ board. We suggest that you crimp an IDC connector onto one end of a length of 10-way ribbon cable. This can then be plugged into CON10 and the wires at the other end separated and stripped to make the required connections. Make sure that the red striped wire goes to the IDC terminal marked as pin 1.

With this cable, some fiddling is required. We couldn't think of an easier way for this short of adding a PCB, which seemed over the top. Pull the wires apart to separate out wires 1 (red), 6 and 7 (together), 8 and 10. Snip the other wires off short as they are not needed. Mark wires 7 and 8 as '–' with some heatshrink or colour it with a permanent marker.

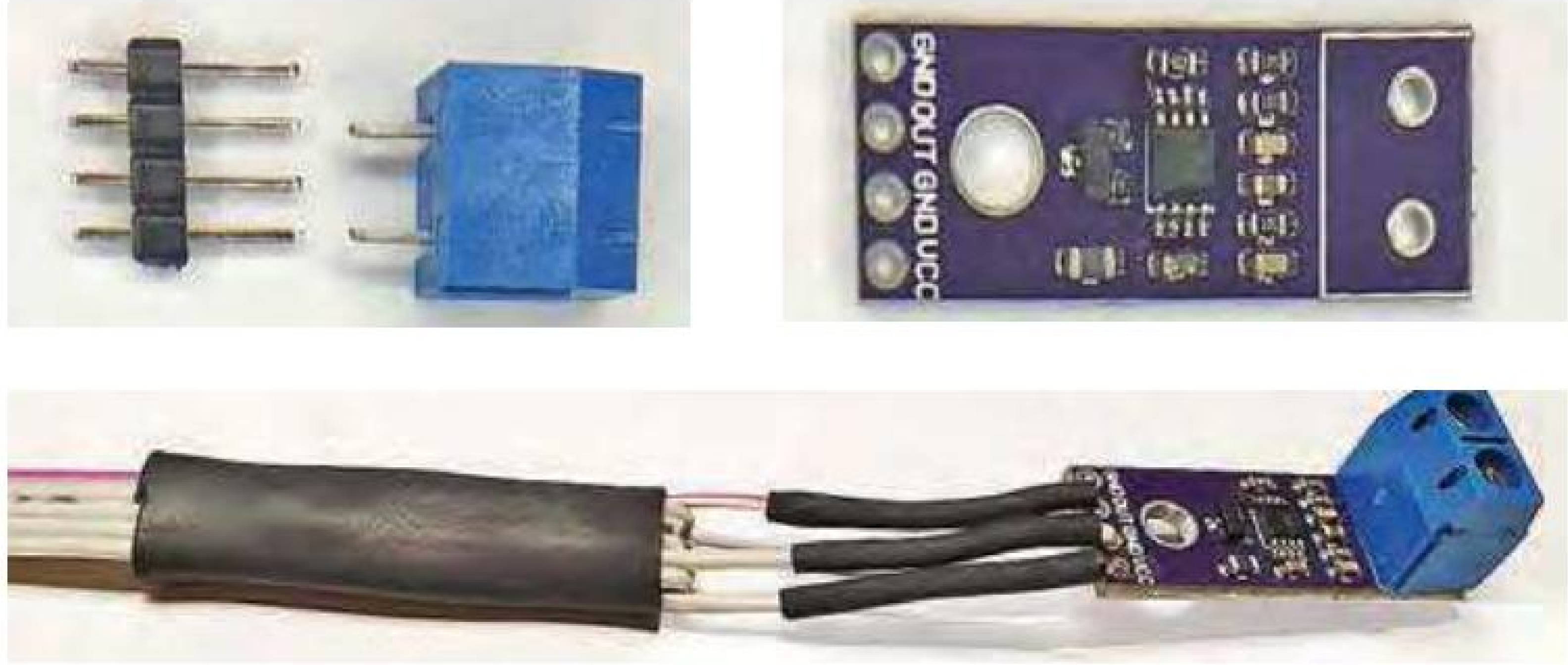
Connect wire 6 to the solid-state relay input + terminal, and wire 7 to the SSR – input. These can be wedged under the screw terminals; do them up tight.

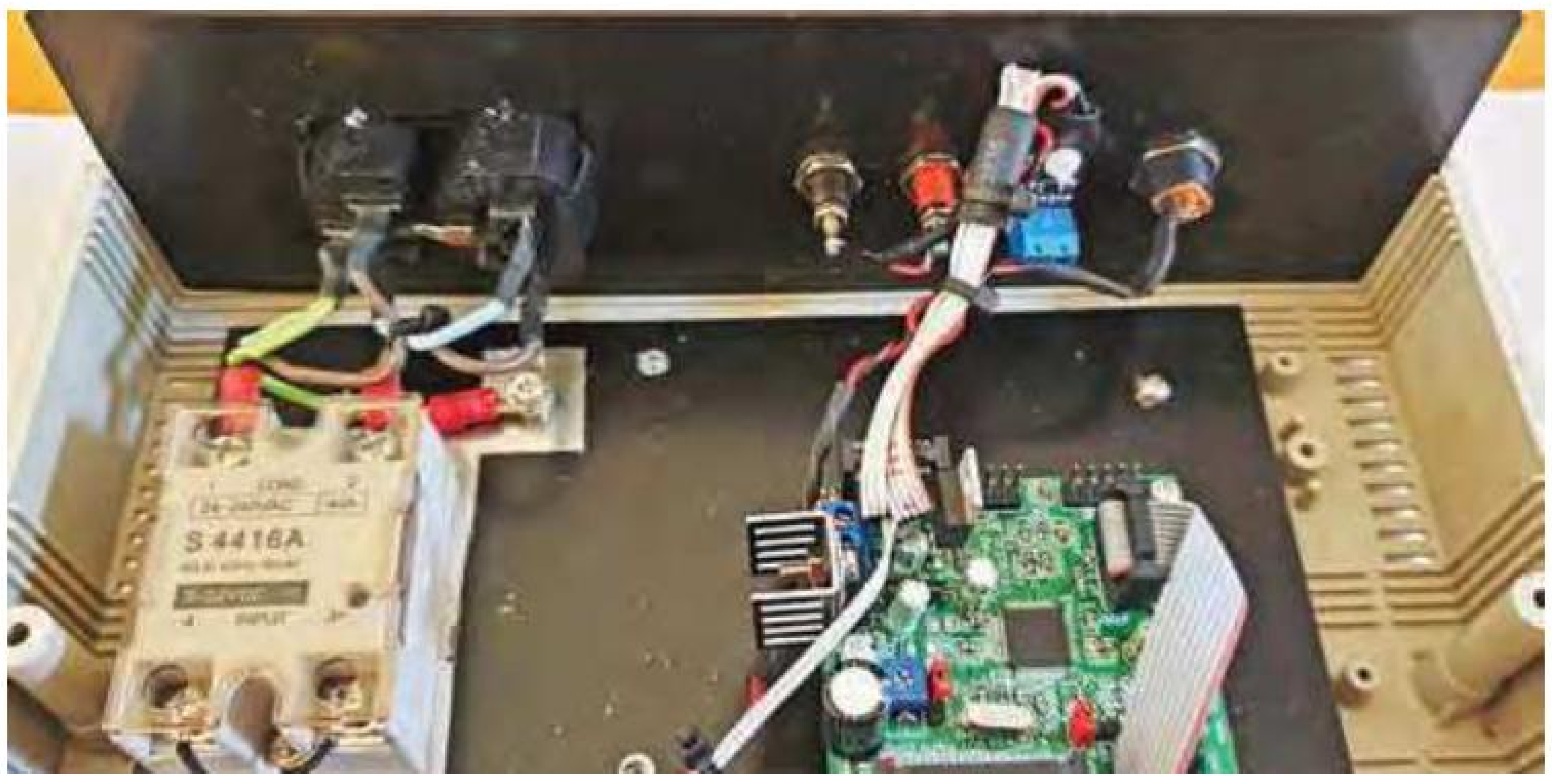
Connect wire 1 to the 'Out' connection of the thermocouple amplifier, wire 8 to its ground and wire 10 to the positive power input on the thermocouple amplifier.

We arranged the cable lengths so that it is possible to encapsulate the thermocouple amplifier in heatshrink tubing and zip tie it to the binding posts. This places the thermocouple amplifier in reasonable contact with the thermocouple plugs. Remember that this amplifier has correction circuitry that accounts for the temperature of the thermocouple plug, so the closer it is to this plug, the better.

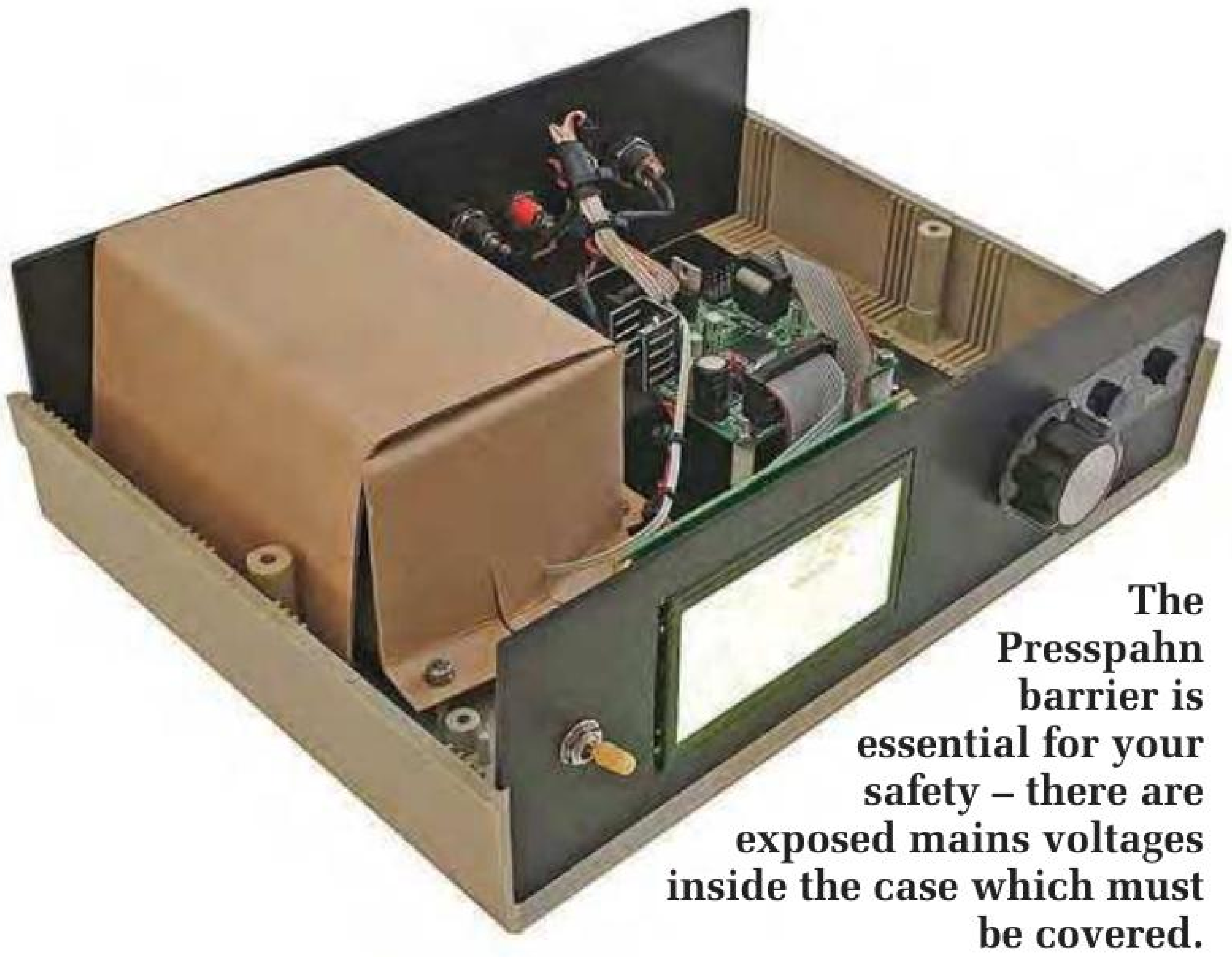
If you purchased the recommended thermocouple amplifier with a purple PCB, there will be a mounting hole. You can use this to mount it to the rear panel with a nylon machine screw and nut, close to the binding posts/banana sockets.

The thermocouple amplifier we used has a purple PCB. If you search ebay or AliExpress for 'AD8495', then you should be able to find one which looks like ours.





A view of the rear panel connections – again, this is before the Presspahn insulation barrier is installed. Don't forget it!



The Presspahn barrier is essential for your safety – there are exposed mains voltages inside the case which must be covered.

A male-IEC-plug-to-female mains socket (such as this one from CPC Farnell, part number PL15014) means no modifications are required for the toaster oven.

Tidying it up

Once you've finished all the wiring, use cable ties to tie each bundle of wires together. This is especially important for the mains wiring, which must all be tied together securely, and also the red and black wires from the DC socket to the front panel on/off switch and to CON4 on the control board.

Make sure that these wires are tied so that they can't move around inside the case (eg, by tying them to the nearby ribbon cables) and that if one breaks off at either end, it can't go anywhere.

Now is also a good time to attach the Presspahn insulation barrier to the bottom plate using machine screws, shakeproof washers and nuts. Refer to the photos to see where it goes. Once the lid is on the case, it should isolate the mains section from the rest of the controller.

Initial testing

For the following tests, do not connect the mains lead. Use only the 9V plugpack. Make sure that jumper JP5 on the CPU board is inserted. There must also be a jumper on LK2 in the position shown in Fig.4. You don't need a jumper on LK1; if there is one there, it doesn't matter which position it is on.

Now switch the device on and check the LCD. Adjust the LCD bias voltage using trimpot VR1. This may require some experimentation; the LCD will initially show no image or a washed-out image. Adjust the bias from one end toward the other until you get a good image.

Next, check that the user controls work by pressing the right-hand button (EXIT); a screen with four boxes should appear. Rotate the encoder knob; you should see each of the four quadrants be highlighted in turn.

Now we set the initial PID coefficients. Press the left-hand button/rotary encoder knob (SEL) when the 'adjust PID settings' screen is highlighted. You will be presented with a screen asking if you are sure. Rotate the dial to 'Yes' and click SEL. Enter 100 for P, 0.5 for I and 670 for D.

This configuration is super critical – if you do not do this, the thing will most likely show 0°C, and definitely not work.

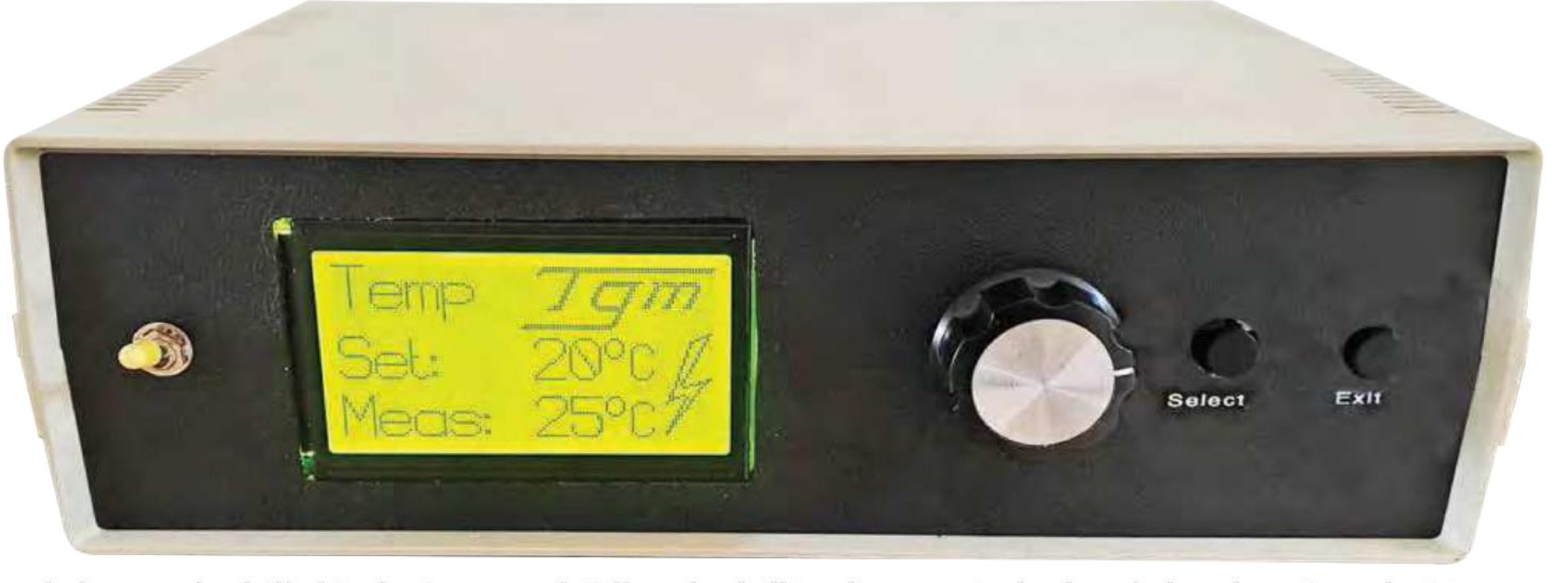
Next, set the reflow settings by pressing SEL when the 'Setpoints' screen is highlighted. You will be presented with a screen asking if you are sure. Rotate the dial to 'Yes' and click SEL. Enter 150C for Preheat Temp and 225C for Reflow Temp.

Then set the Sensor TEMPCO settings by pressing the left button (SEL) when the 'Tempco and Offset' screen is highlighted. You will be presented with a screen asking if you are sure. Rotate the dial to 'Yes' and click SEL. Enter 0 for OFFSET (this is in °C), and 0.161 for TEMPCO.

Check that the home screen now shows approximately the right ambient temperature. Boil a jug of water, insert the thermocouple and check that the home screen shows something close to 100°C. Remember that thermocouples are not super-precise devices, and an error of a few degrees is OK.

To check that the SSR drive is working, use the following steps:

1. Reset the system by cycling the power
2. Set the target temperature a bit above the ambient temperature
3. Watch the LED on the solid-state relay (it is next to the input). This should light up every few seconds, in time with the lightning bolt on the screen going from an outline to a full lightning bolt
4. Turn the set temperature down to around 20°C, and hold the tip of the thermocouple between your fingers, so the measured temperature is above the set temperature
5. Check that after a few seconds, the lightning bolt and red LED on the solid-state relay stop lighting.



Four holes must be drilled in the front panel (follow the drilling diagrams in the downlod package from the May 2021 page of the *PE* website) but there is also a cutout required for the display. We used a Dremel to cut out the rough hole then finished it off with a fine file. The same approach can used for the IEC mains socket cutout on the rear panel.

Pin	Role	Connect to
1	Analog input	Thermocouple amplifier output
6	Heater control	SSR input 3+
7	GND	SSR input 4-
8	GND	Thermocouple amplifier GND
10	+3.3V	Thermocouple amplifier power supply

Table 1 – CON10/PORTB connections (other pins not used)

Note that with a PID controller, there can be a lag in its response to changes in temperature and settings.

Live testing

You can now switch off the power and connect the oven to the IEC mains output socket on the controller via the IEC/mains socket adaptor.

Before connecting the mains input IEC lead, double-check your wiring, and ideally have a friend triple check it. Check that:

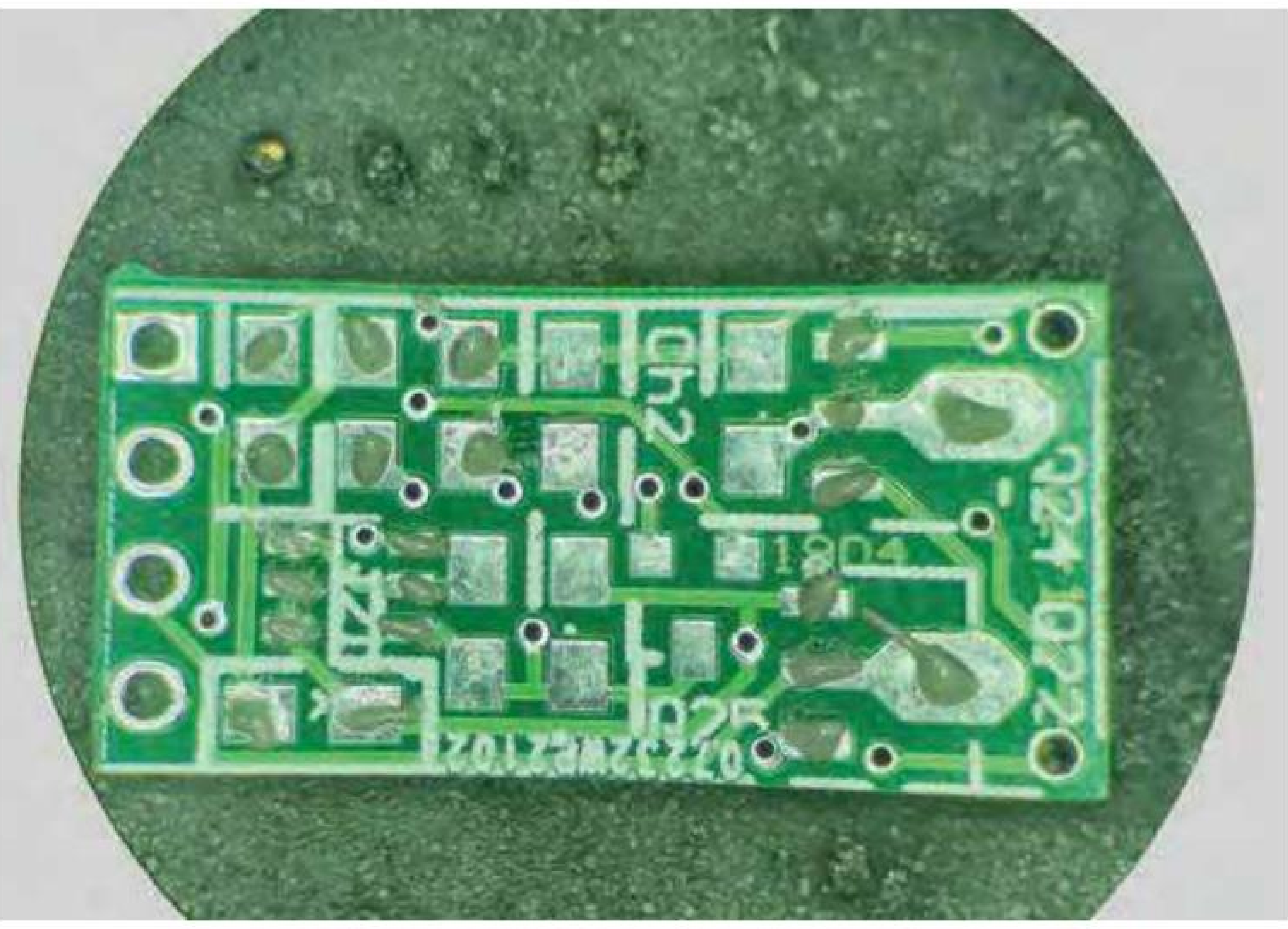
- No stray wires are poking out of crimps, terminals or the insulation
- There are no wires stripped too far, leaving lots of exposed copper that could contact with something
- The IEC 'N' connector goes to the other IEC 'N', diagonally across the connector
- The earth connector is solidly connected to the baseplate
- One wire from each of the IEC live pins goes to one SSR 'LOAD' terminal.

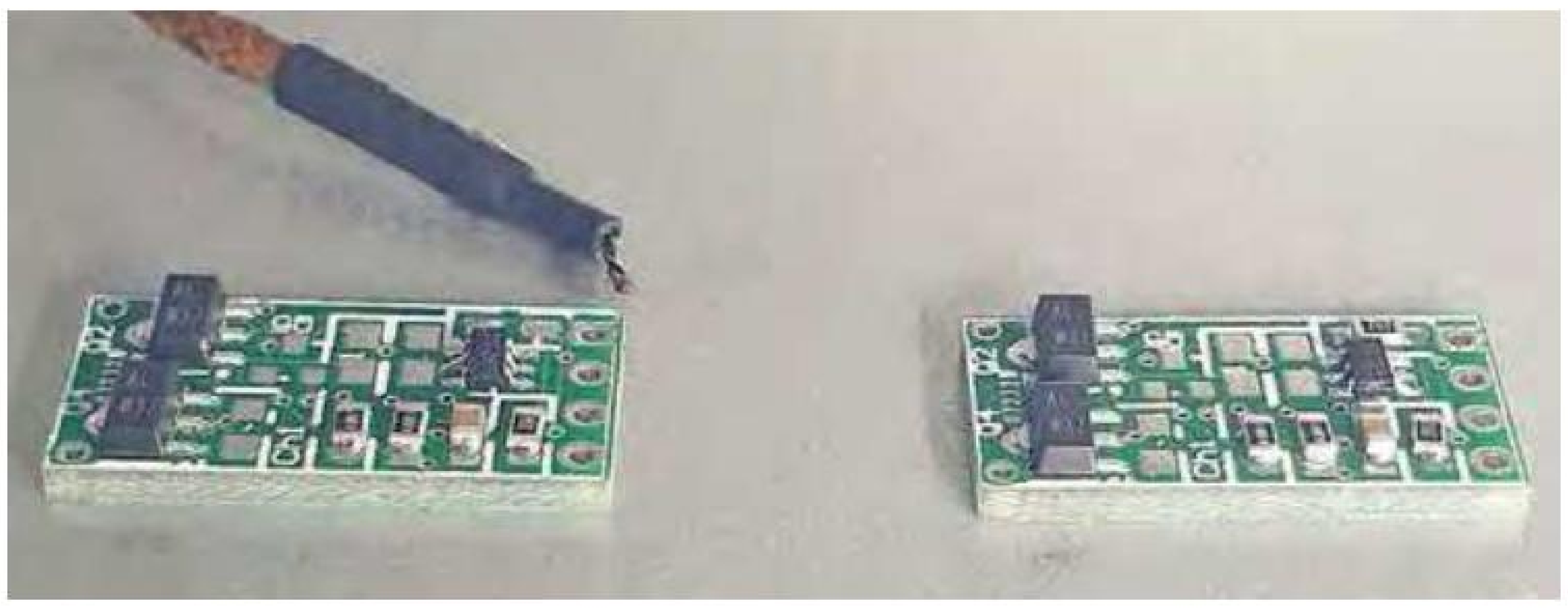
Close the case and securely screw it together; make sure there are no exposed mains wires. Turn the oven to its maximum temperature setting, and then switch on all elements. Dial the timer for 20 minutes or so, plug the oven into the controller, power up the controller and set the temperature to 20°C. Plug the controller into the mains and switch it on.

The oven should not be on yet, unless your house is particularly cold. Turn the dial on the controller for a setting of 40°C. You should soon see the lightning bolt on the controller coloured in, indicating the heater is on. If your oven is like ours, you should see a light on the oven indicate it is switched on. After a few seconds, you should see the measured temperature start to creep up.

The thermal inertia of the oven will cause a delay of 20 seconds or so; the temperature will likely overshoot the target. As explained above, our controller is optimised for high temperatures, and you will see overshoot in the order of 15°C or so at low temperatures. Just watch to see that heating switches off before it reaches the target temperature.

Try setting the controller to 60°C, and watch the controller switching on and off. Once heated, the oven takes quite a while to cool down. Remember that when reflowing, you must open the door at the end of the cycle.



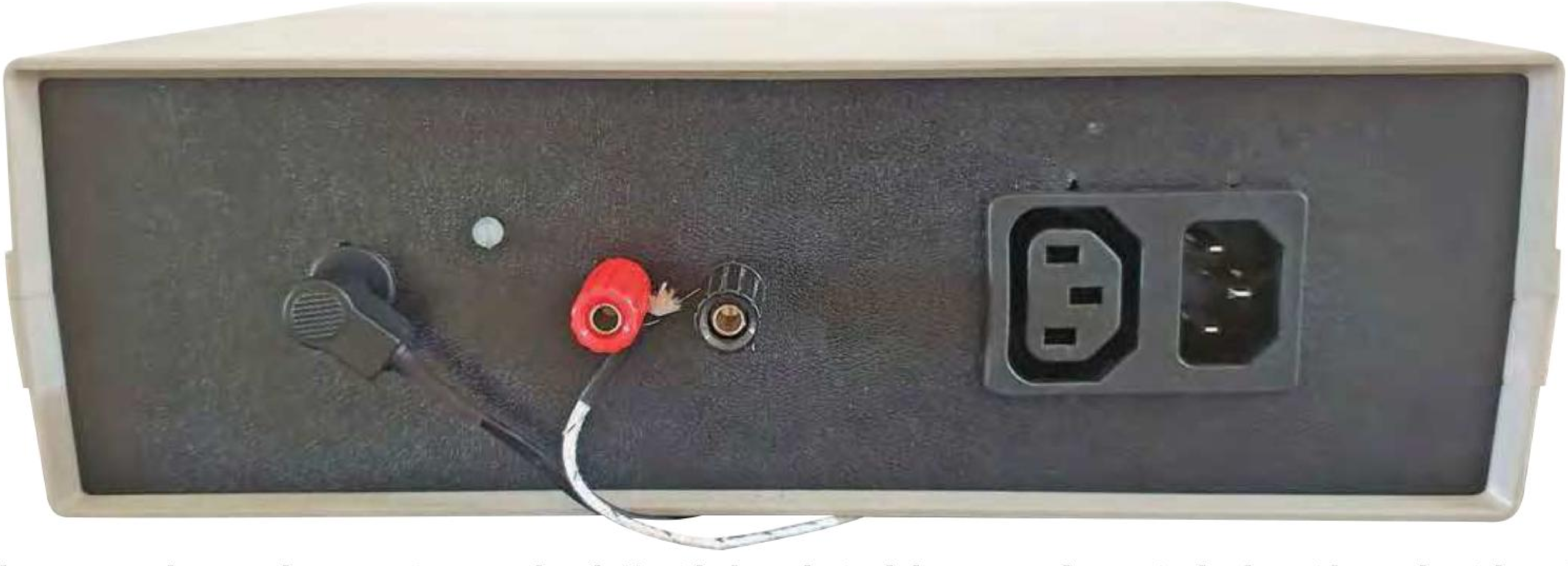


Above: the board used during reflow test, showing solder paste applied to pads. The amount shown here is more than enough! Below: some sample boards during reflow test.

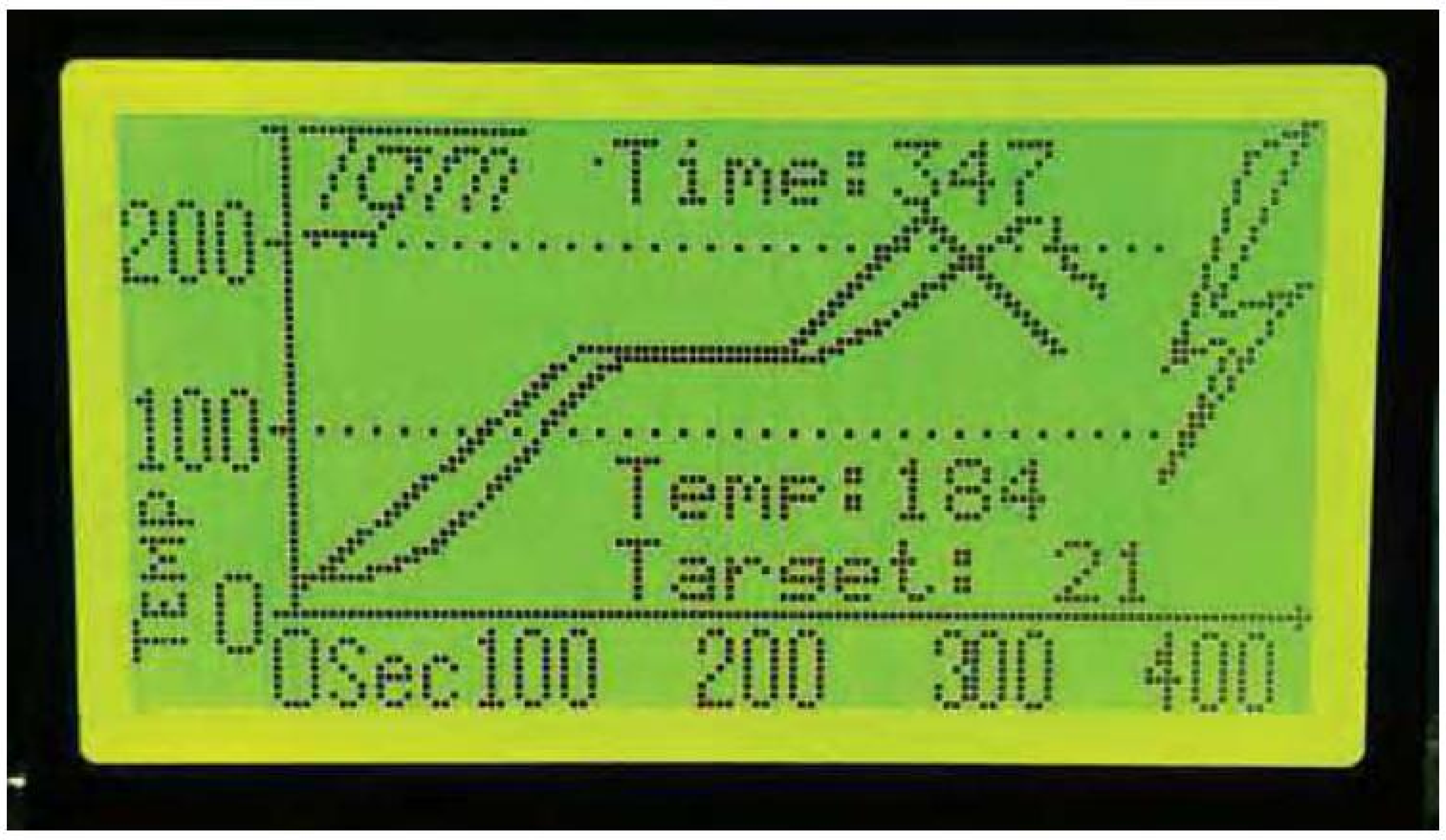
Reflowing

We reflow soldered a couple of boards with SMD components to demonstrate the operation of the oven. As shown in the pictures below, if you are applying solder paste by hand, use a syringe and put less than you think it will take! The biggest mistake most people make when reflow soldering parts is to add too much solder paste.

We stuck the thermocouple to the edge of the oven using tape, and fiddled it until the thermocouple was close



The rear panel sports the 9V DC input socket (left) with the polarised thermocouple terminals alongside. At the right end is the twin IEC mains output/input socket which is the raison d'etre for this project: mains comes in to the right-hand (male) socket; controlled mains to the toaster oven comes out of the left-hand (female) socket.



Reflow display showing target and actual temperature profiles.

to the test PCBs. You need the sensor to be as close as possible to the boards (maybe even touching), to ensure the temperature profile achieved is right in the vicinity of your board.

The temperature profile that the oven ran is shown above. You can see that the temperature fell after we opened the door a crack. We left it like that for about 20 seconds, then opened it fully to allow the board to cool. Don't move the board until it cools, as the solder will still be liquid for a while!

At about 180°C, the flux activates and the solder starts to reflow. By the time the oven hit 225°C, and we opened the door, the board had fully reflowed and settled down. Ideally, you should give your oven a trial run on a non-critical PCB before soldering anything really expensive.

But if you have a hot air rework station, you can probably fix anything that goes awry on the first couple of tries, until you get it fully dialled in.

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Help, it's not working!

Nothing on the LCD screen

- Check that the LCD bias pot is set correctly. Turn it fully anticlockwise, then slowly turn it clockwise until you see something on the display
- Check that the microcontroller is running
- Check your parts and soldering, especially look for bridges across the microcontroller pins
- Check the output of the 5V and 3.3V regulators.

My oven is going crazy

- Have you used an oven with a smart controller? This project won't work with it!

The temperature readings are very wrong

- Is the thermocouple connected backwards
- Are the tempco and offset in the software right for your amplifier
- Use a DVM to check the voltage on the thermocouple amplifier output. It should be about 1.25V. If not, read the panel on thermocouple amplifiers
- Put the thermocouple tip in a cup of hot water. Watch to see if the voltage increases.

The temperature readings are slightly wrong

- Is your thermocouple in the oven next to your workpiece
- Check the thermocouple tempco and offset is correct for your thermocouple
- Try putting the sensor tip in iced water and boiling water. If the readings are off by more than a few degrees, check for construction errors.

The oven won't heat

- Ummm – you did check that the oven worked normally before making any modifications, didn't you?!
- Check that your oven's temperature is set to maximum and that it is switched on and both heating elements are selected.
- Is the thermocouple reading the right temperature?
- Set the temperature on the controller for say 100°C and watch the SSR. It has a red LED that indicates when it is on
- Watch your oven power light. Is it switching on in unison with the SSR light?

The oven is running too hot when set for fixed temperatures

- At low temperatures, even with the optimisations we made, the thermal mass of the oven means that there is still a lot of overshoot. Also, the thermal mass of the elements and oven means it takes a long time to cool down
- Try starting it up in advance and give it time to settle before using it.

Settings are lost at power-off

- Use the save option after making changes.
- Check the PIC microcontroller pins for shorts on the side close to the EEPROM
- Check the orientation and soldering of the EEPROM chip.

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Max's Cool Beans

By Max the Magnificent

Flashing LEDs and drooling engineers – Part 15

Every now and then,* a once-in-a-generation mind appears on the scene (*by some strange quirk of fate, this occurs approximately once in a generation). Such a mind sees things beyond the ken of the average Joe or Josephina, shining the bright light of understanding on previously unsurmountable problems, rending the veils asunder, and revealing the mysteries of the universe.

The great John Conway observing his *Game of Life* cellular automoton program on an early computer screen.

What? Who? Me?

Well, you are very kind, and I can see how you might have come to that conclusion (especially if you've been talking to my dear old mother), but I was actually talking about the English mathematician John Horton Conway (1937–2020), who made his appearance in the generation before mine, thereby ensuring that future historians would not be obliged to pick and choose between us.

Speaking of generations, I'm reminded of the question I posed in, *With Which Generation Do You Identify Yourself?* (**https://bit.ly/3brBsfv**), where I asked: 'Are you from the Silent Generation, a Baby Boomer, a member of the Generation Jones crew, a Millennial, or do you have 'Generation X, Y, or Z' tattooed on your forehead?' As for myself, I'm a proud member of Generation Jones (seriously; it really is a thing – **http://bit.ly/318NfcD**).

It's alive!

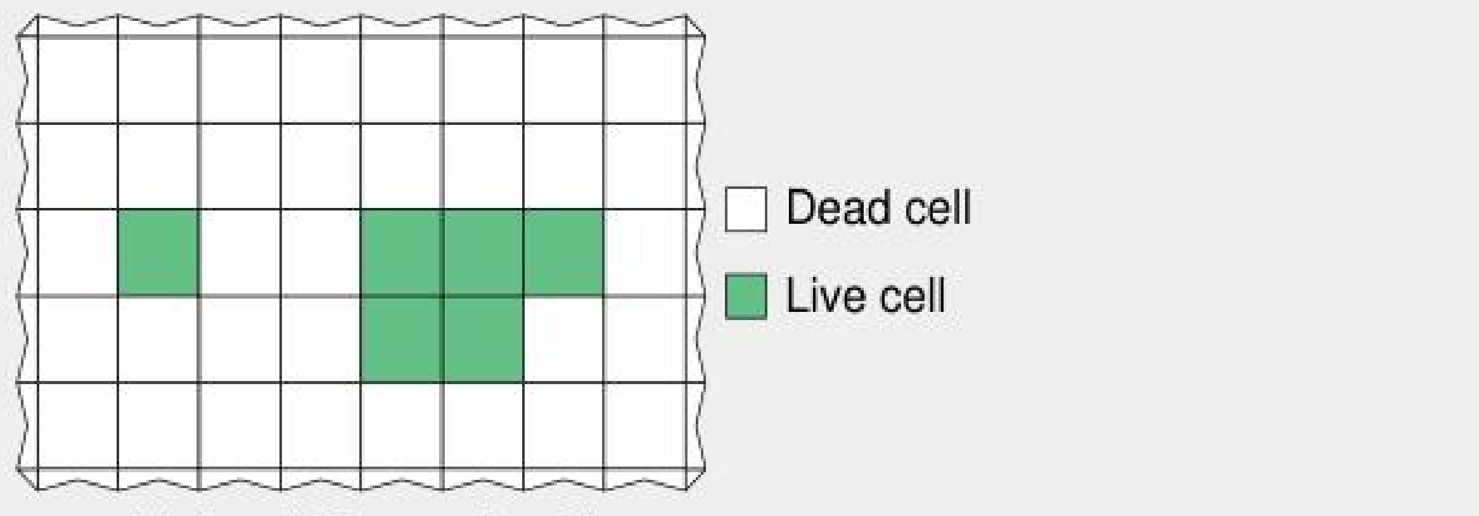
Conway was a larger-than-life character who has been described as 'Archimedes, Mick Jagger, Salvador Dali, and Richard Feynman all rolled into one.' Among his many contributions to diverse branches of mathematics, Conway invented (maybe we should say 'discovered') the 'surreal numbers'. As the Wikipedia observes, 'If formulated in Von Neumann-Bernays-Gödel set theory, the surreal numbers are a universal ordered field in the sense that all other ordered fields, such as the rationals, the reals, the rational functions, the Levi-Civita field, the superreal numbers, and the hyperreal numbers, can be realised as subfields of the surreals.' Well, duh!

Of particular interest to us here is that Conway was the originator of a famous two-dimensional cellular automaton (plural cellular automata, abbreviation CA) now known as *Conway's Game of Life* (*GOL*), which he unleashed on the world in 1970. The 'universe' in which the *GOL* takes place is an infinite, two-dimensional orthogonal grid of square 'cells,' each of which is in one of two possible states, 'live' or 'dead.' Every cell interacts with its eight 'neighbours,' which are those cells that are horizontally, vertically or diagonally adjacent.

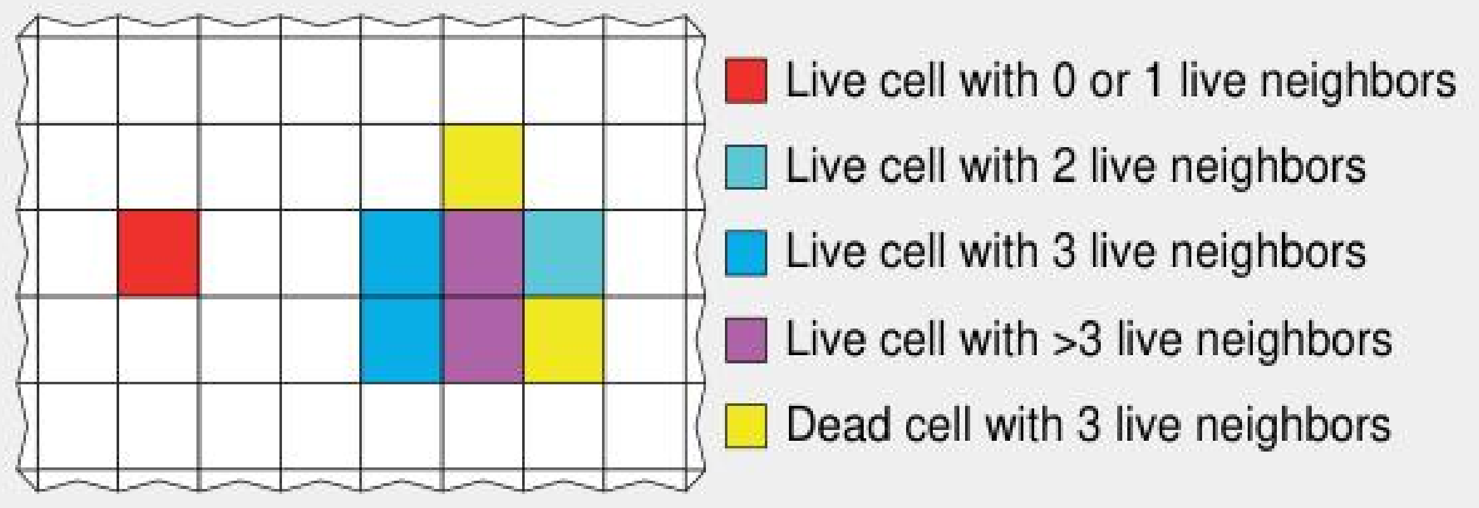
At the beginning of the game, the universe is populated with an initial pattern, which constitutes the 'seed' of the system. The game then evolves from generation to generation according to the following rules:

1. Any live cell with fewer than two live neighbours dies, as if by underpopulation.
2. Any live cell with two or three live neighbours lives on to the next generation.
3. Any live cell with more than three live neighbours dies, as if by overpopulation.
4. Any dead cell with exactly three live neighbours becomes a live cell, as if by reproduction.

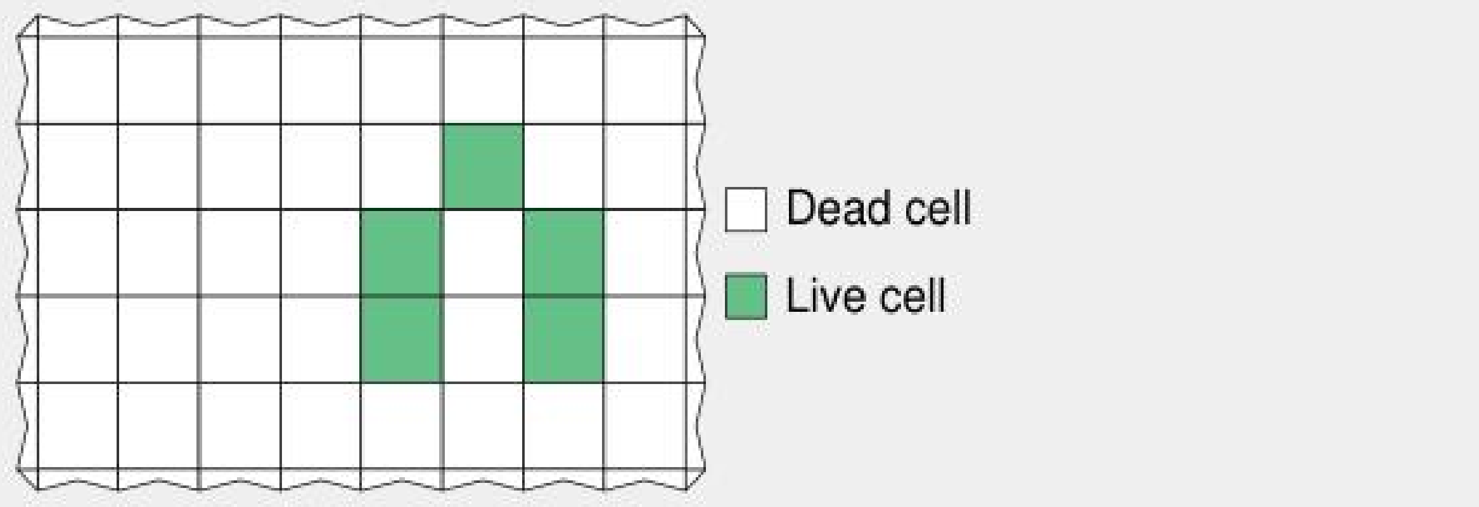
The first generation is created by applying the above rules simultaneously to every cell in the seed generation. Births and deaths occur simultaneously, and the discrete moment at which this happens is sometimes called a 'tick.' Each generation



(a) Seed (Generation 0)


🟥 Live cell with 0 or 1 live neighbors
Live cell with 2 live neighbors
🟦 Live cell with 3 live neighbors
🟪 Live cell with >3 live neighbors
🟨 Dead cell with 3 live neighbors

(b) Evaluating Generation 1



(c) Generation 1

Fig.1. A simple example reflecting a small portion of the universe.

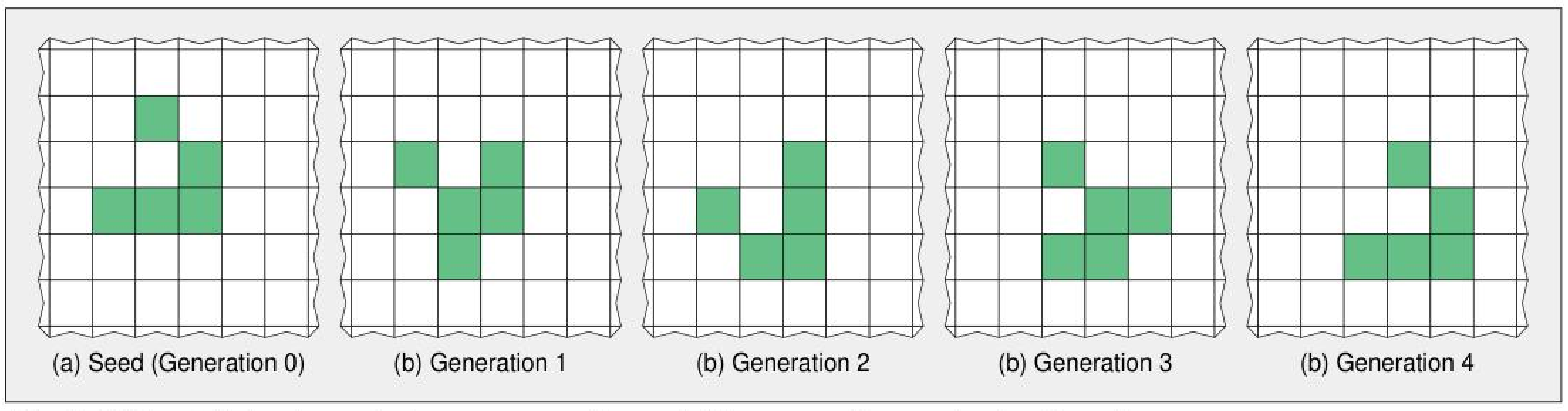


Fig.2. This Glider translates across the grid in a south-easterly direction.

is a pure function of the preceding one. The rules continue to be applied repeatedly to create further generations.

Let's consider a simple example to get our mental juices flowing (don't worry, we'll mop everything up later). We'll start by looking at a small part of the universe that's been seeded as illustrated in Fig.1a. We will consider this to be Generation 0. Next, we start to evaluate the new generation, which will be Generation 1 in this case (Fig.1b). As we see, there's one live cell that doesn't have any neighbours, so that cell won't make it to the next generation (as if by underpopulation). We have one live cell that has two live neighbours and two live cells that have three live neighbours, all of which will survive to the next generation. We have two live cells with four live neighbours, which means they won't survive (as if by overpopulation). And we have two dead cells that have three live neighbours, so these will spring to life in the next generation (as if by reproduction). Once we apply all of these rules, the new generation, Generation 1, will be as shown in Fig.1c.

Although the *GOL* may appear to be simple at first, this is deceptive because there are hidden layers of sophistication. For example, different groupings of live cells can result in very different behaviors from generation to generation. Some patterns are known as 'Still Lifes' because they don't change from one generation to another unless something happens to disturb them. Slightly more complicated are the 'Oscillators,' which will return to their initial state after some finite number of generations.

Things start to get really interesting when we meet patterns that can translate (move) themselves across the universe (grid or array). The first of these patterns, and the simplest, is called the 'Glider', which was discovered by Richard Guy in 1970. Consider the Glider shown in Fig.2. After four generations we see the original patten reappear, but it's moved one cell to the right and one cell down as compared to its original location in Generation 0. If we keep on running, the Glider will continue to make its way across the array.

When you first meet the rules for the *GOL*, you might think of them as being relatively easy to define. In reality, it took Conway and his colleagues a lot of time and mental effort to arrive at an ideal balance that wouldn't result in the game experiencing rapid underpopulation or overpopulation. The amazing thing to me is that Conway didn't have access to a computer when he developed these rules. Instead, he used the board and pieces from the game of Go to experiment with alternative scenarios. (If you want to learn more about Conway, one book I really enjoyed (but that may now be out of print) is *Genius at Play: The Curious Mind of John Horton Conway* by Siobhan Roberts: **https://amzn.to/3kSZCT5**).

Great (ping-pong) balls of life!

On the off chance you've only just started subscribing to *Practical Electronics*, I should probably make mention of the fact that, since the March 2020 issue, here in the world of *Cool Beans* (where the flowers are more colourful and smell nicer, the butterflies are bodacious and brighter, and the birds are fluffier and sing sweeter), we've been performing experiments with a 12×12 array of ping-pong balls, each equipped with a tricolor LED in the form of a WS2812B (a.k.a. 'NeoPixel') device.

What we are going to do is to implement a simple *GOL* on our 12×12 array, but we immediately run into a problem, which is the modest size of our universe (array). Do you recall earlier when we noted that, 'The universe of the *GOL* is an infinite, two-dimensional orthogonal grid of square cells'? Well, our universe is only 12×12 cells in size, which some may feel to be a tad less imposing than 'infinite'.

Of course, the 'infinite' descriptor is associated with a theoretical *GOL*. In practice, every *GOL* creator has to handle a bounded universe by one means or another. In my previous column (*PE*, April 2021), we discussed three ways in which we could treat the edges of our universe. We called the first option 'Keep on trucking.' The idea here is that when something like a Glider in the *GOL* reaches the edge of the array it disappears from the picture and we all shrug our shoulders and pretend that it's heading out into the great beyond.

We referred to our second option as 'Bouncing off the edge.' As this name implies, when something reaches the edge of the array, it bounces back into the body of the array. Now, although this was easy to achieve with the individual pixels discussed in my previous column, it would be a lot harder to implement for something like a *GOL* Glider. If we were desperate to realise a 'Bouncing off the edge' scenario in our *GOL* simulation, one approach we might try would be to

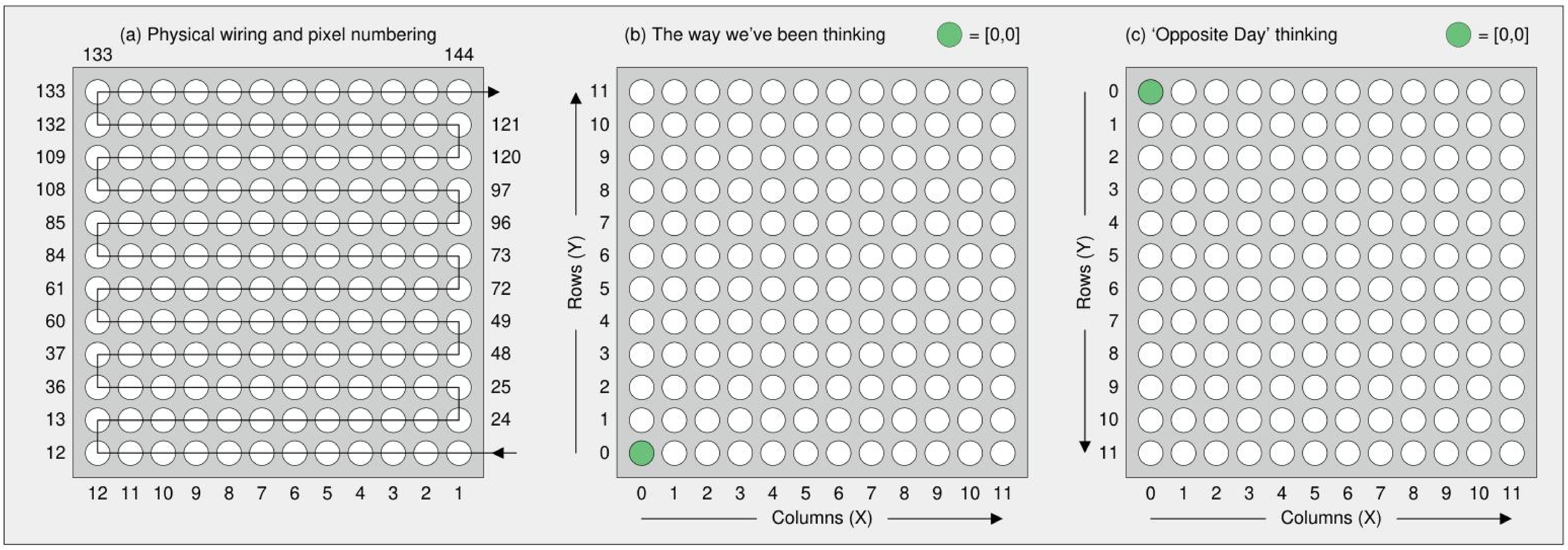


Fig.3. Welcome to 'Opposite Day' thinking.

implement a 1-pixel wide band of imaginary pixels surrounding our array containing virtual cells that are permanently alive (or dead).

Our third option was the 'Curved spacetime' scenario, in which we imagine the universe (in the form of our ping-pong array) as being curled into a vertical cylinder such that the right-hand side is joined to the left-hand side, while simultaneously being curled into a horizontal cylinder such that the upper side is joined to the lower side. In this scenario, when something like our *GOL* Glider passes through the right-hand edge of our array, for example, it will reappear on the left-hand side of the array. It's this 'Curved spacetime' scenario that we are going to implement for our *GOL*.

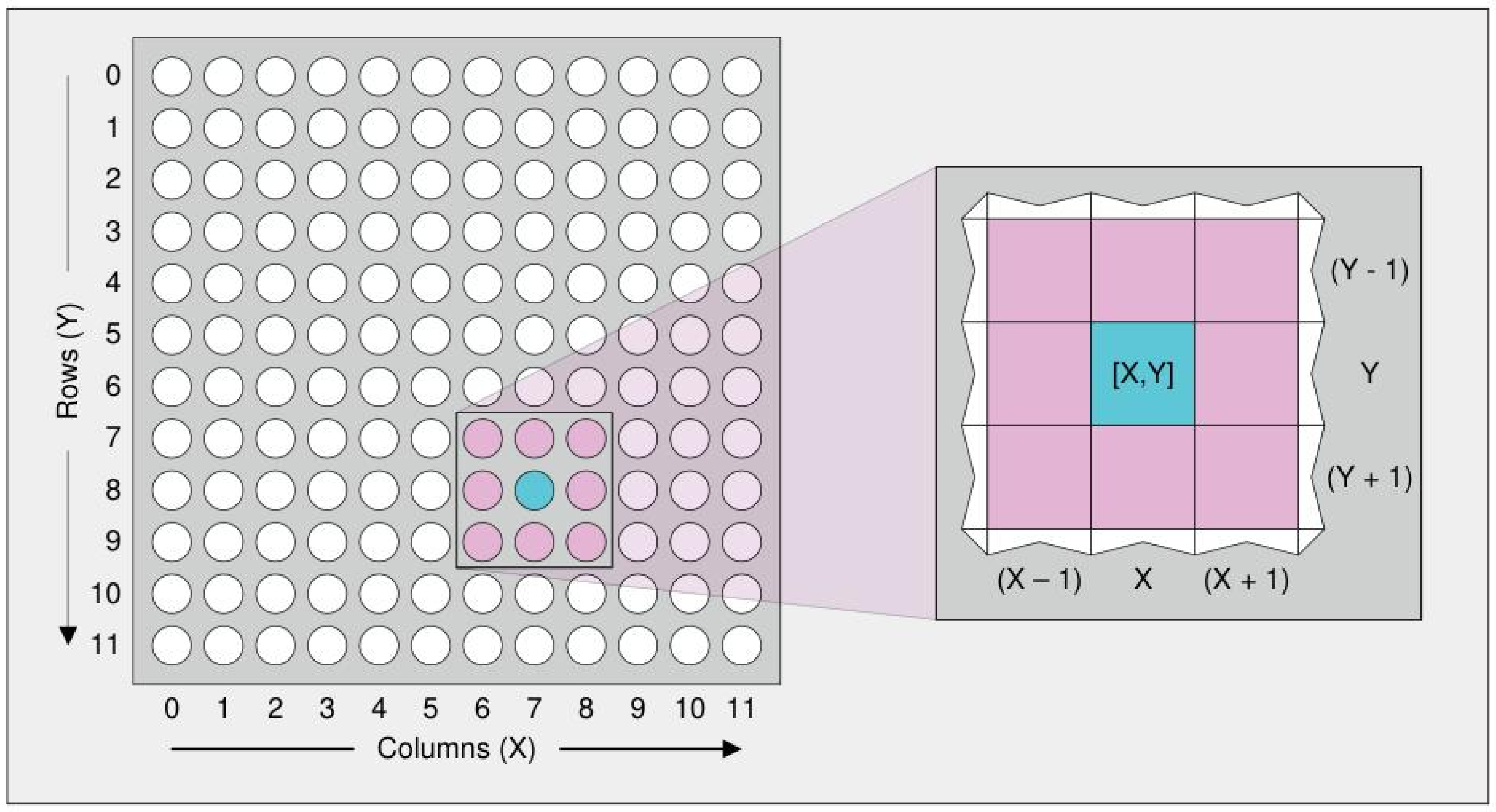


Fig.4. If only we didn't have to take the edges into account.

Opposite day

Have you ever watched the American animated comic series SpongeBob SquarePants? In one of the episodes in Season 1, Squidward tells SpongeBob that it is 'Opposite Day,' which means everyone must act opposite to how they usually act. The reason I mention this here is that, as you may recall from our earlier discussions on the physical construction of the array (*PE*, August 2020), looking from the front, the pixels are wired in a serpentine fashion commencing in the lower right-hand corner and progressing back and forth until we reach the upper right-hand corner (Fig.3a).

In the real world, these pixels are numbered from 1 to 144 (we also have a 'sacrificial' pixel 0 that acts as a voltage level shifter and that isn't visible from the front of the array). For reasons that made sense at the time, we decided to visualise the array as comprising 12 columns (the X axis) and 12 rows (the Y axis), both numbered from 0 to 11, with location [X,Y] = [0,0] appearing in the lower left-hand corner of the array (Fig.3b). As part of this, we created a `GetNeoNum()` function that accepts X and Y values and returns the corresponding number (`iNeo`) of the pixel in the array. The core of this function, which we've been using in all of our programs since the beginning, was as follows (where `NUM_XY` is defined as 12):

```
iNeo = yInd * NUM_XY;

if ( (yInd % 2) == 0)
{   // Even row
    iNeo = iNeo + (12 - xInd);
}
else
{   // Odd row
    iNeo = iNeo + (xInd + 1);
}
```

In order to refresh yourself as to how this works, jot down a couple of sample [X,Y] combinations on a piece of paper and then run them through this function as a mental exercise. For example, if we assume [X,Y] = [0,0], then when we apply these values to our function it returns 12, which is the physical number of the pixel in the lower left-hand corner. Hurray!

Unfortunately, for reasons that will become apparent as we proceed, when it comes to our implementation of the *GOL*, it's going to make our lives a lot easier if we think of location [X,Y] = [0,0] as appearing in the upper left-hand corner (Fig.3c).

There are a variety of solutions we could employ, but the easiest way to make this happen is to modify our `GetNeoNum()` function so that it returns the values we want to see. Why don't you ponder this for a while to determine what changes need to be made (you'll find my solution at the end of this column).

Happy dance or bad-hair day?

Before we plunge into the fray with gusto and abandon, let's pause for a moment to cogitate, ruminate, and deliberate on what we wish to do. When it comes to evaluating which cells are going to perform their 'happy dance' and which are going to have a 'bad hair day' in the next generation, one of our tasks is going to be determining how many live neighbours each cell currently has.

Let's start by playing a simple thought experiment. Let's assume we are interested only in a single cell referenced by [X,Y] that's located somewhere in the middle of our array and we want to determine how many of its neighbours are alive (Fig.4).

Purely for the sake of this experiment, let's assume that we've declared a two-dimensional (2D) array of cells called `Cells[NUM_Y][NUM_X]`, where `NUM_Y` and `NUM_X` have both been defined as 12. For reasons that will become apparent, we are going to visualise this array as being presented in the form `Cells[Y][X]` (as opposed to `Cells[X][Y]`, which would be a tad more intuitive). Let's also assume that these cells can be in one of two states: `ALIVE` or `DEAD`. Furthermore, let's assume that we've declared an integer called `numNeigh` in which we are going to record the number of neighbouring cells that are alive. If we don't have to account for the effects at the edges, we can simply employ `dY` ('delta Y') and `dX` ('delta X') values that each range from –1 to +1 as follows:

```
numNeigh = 0;

for (int dY = -1; dY <= 1; dY++)
   for (int dX = -1; dX <=1; dX++)
      if ( !( (dX == 0) && (dY == 0) ) )
         if (Cells[Y + dY][X + dX] == ALIVE)
            numNeigh = numNeigh + 1;
```

The way this works is that the nested `for()` loops take us through every one of the nine cells in the 'cluster' centered on the cell at [X,Y]. The first `if()` test makes sure that we aren't counting the cell at [X,Y] itself. The second `if()` test checks to see if the surrounding cell in question is `ALIVE` and, if so, increments our count of live neighbours.

Before we proceed, let's remind ourselves that, in the not-so-distant past, microcontrollers were much less powerful than they are today. At that time, it was important to conserve every clock cycle and/or memory location. In fact, this may still be the case in some of today's real-world systems. Assuming our goal is to minimise clock cycles, how might we modify our code snippet above? Well, one way would be as follows:

```
if (Cells[Y][X] == ALIVE)
   numNeigh = -1;
else
   numNeigh = 0;

for (int dY = -1; dY <= 1; dY++)
   for (int dX = -1; dX <=1; dX++)
      if (Cells[Y + dY][X + dX] == ALIVE)
         numNeigh = numNeigh + 1;
```

What we've done is to take the test that makes sure that we aren't counting the cell at [X,Y] itself outside of the nested loop in which it used to be performed nine times. Instead, we've replaced it with a single test outside the loop that uses the state of this cell to initialise our `numNeigh` count variable. If cell [X,Y] is alive, we set `numNeigh` to –1, which means that when we come to count this cell in the nested loop, it cancels itself out, if you see what I mean.

Master the modulo

Of course, we do need to handle the cells at the edge of the array. Let's remind ourselves how we dealt with this in our previous column. Purely for the purposes of providing an example, consider a single row of 12 ping-pong balls numbered left-to-right from 0 to 11. Now assume we are looking at pixel 6 (Fig.5).

I'm not going to repeat our previous discussions. The important part is that if we are looking at pixel 6, then the pixel to the left will be `(Pixel + M1) % NUM_XY`, which equates to (6 + 11) % 12 = 17 % 12 = 5. Similarly, the pixel to the right will be `(Pixel + P1) % NUM_XY`, which equates to (6 + 13) % 12 = 19 % 12 = 7.

The important part of all this is that this technique implements our curved spacetime universe. In the case of pixel 11, for example, the pixel to the right will equate to (11 + 13) %12 = 24 %12 = 0. Similarly, in the case of pixel 0, the pixel to the left will equate to (0 + 11) % 12 = 11 % 12 = 11. Once again, I feel a little 'Tra-la' wouldn't go amiss.

Unfortunately, there is a slight 'gotcha' because we can no longer directly use `dX` and `dY` delta values ranging from –1 to +1. On the other hand, this is a small issue in the scheme of things. Assume that we've already defined our `M1` and `PI` values as illustrated in Fig.5. Also, that we've defined `NUM_DELTAS` ('number of delta values') as being 3. Consider the following snippet of code, which will work for any cell in the array, including the little rascals at the edges:

```
int Deltas[NUM_DELTAS] = {M1, 0, P1};

if (Cells[Y][X] == ALIVE)
   numNeigh = -1;
else
   numNeigh = 0;

for (int dY = 0; dY < NUM_DVALS; dY++)
   for (int dX = 0; dX < NUM_DVALS; dX++)
   {
      int tX = (X + Deltas[dX]) % NUM_XY;
      int tY = (Y + Deltas[dY]) % NUM_XY;

      if (Cells[tY][tX] == ALIVE)
         numNeigh = numNeigh + 1;
   }
```

I don't know about you, but when I look at this it makes me think that it's almost as if we had a plan. Sad to relate, if that's what *you* think, then you'd be sadly mistaken because I am literally making this up as we go along.

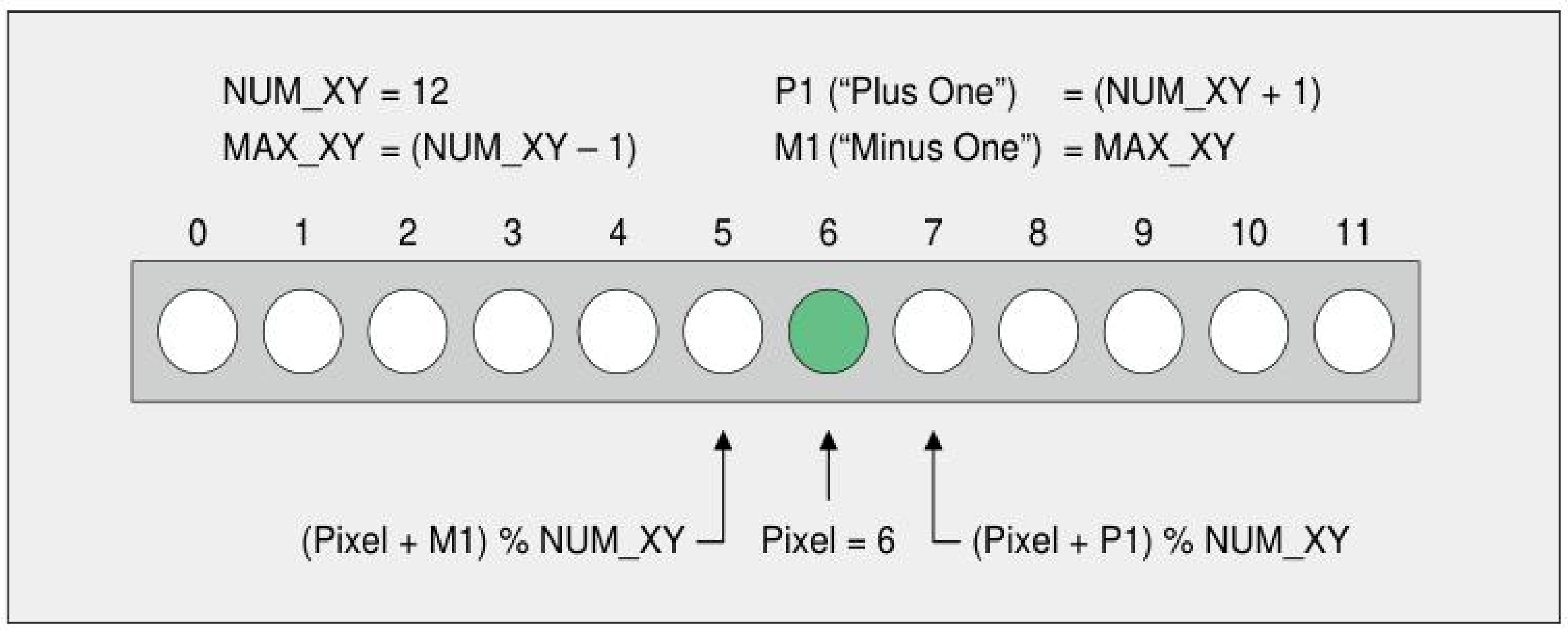


Fig.5. The masterful % modulo operator.

One is the loneliest number

Do you recall the song 'One' (more commonly thought of as 'One is the loneliest number'), which was originally written and recorded by Harry Nilsson? This song was made famous by the American rock band Three Dog Night, whose recording in the key of F minor reached number five on the US Billboard Hot 100 in 1969.

I loathe this song with a passion. The only reason I mention it here is to remind ourselves that all we've done so far is to consider the processing of a single hand-picked cell. We're going to have to scale this up to evaluate every cell in our array. Also, we're going to have to use this information to determine which cells will live and which will die in the next generation.

At this stage it would be a great idea for you to print out the entire sketch (program) so you can follow along (file **CB-May21-01.txt**, which is available on the May 2021 page of the *PE* website **https://bit.ly/3oouhbl**). We won't go through the entire program here, but let's take a quick peek at a couple of key elements.

First, we declare two enumerated types as shown below (we introduced the concepts of `typedef` (type definitions), `enum` (enumerated types), and `struct` (structures) in *Tips and Tricks*, *PE*, December 2020):

```
typedef enum nGenOptions
{
   ALIVE,
   DEAD
};

typedef enum xGenOptions
{
   STAYING_ALIVE,
   DYING,
   STAYING_DEAD,
   COMING_ALIVE
};
```

We also define a structure called `CellData` and then we declare a two-dimensional (2D) array called `Cells[][]`, where each element of the array is a copy of our structure as follows (`nGenState` is the state of the cells in the current generation; `xGenState` is what we are going to use to define the state in the next generation; and `numNeigh` is the number of live neighbours):

```
typedef struct CellData
{
   nGenOptions nGenState;
   xGenOptions xGenState;
   int         numNeigh;
};

CellData Cells[NUM_Y][NUM_X];
```

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The mechanical engineering side of the project is relatively straightforward and is likely to involve little more than a cooler, a pump, some solenoid valves, a few system monitoring sensors (flow/pressure/temperature) and connecting plumbing. However, understanding and appreciation of the engineering requirements of handling food served to the public is critical.

At this stage the design is open-ended, so it is not tied to a particular microcontroller platform. The machine will not be expected to accept traditional cash.

If this sounds like your kind of challenge then please email me at: **iancrosby668@gmail.com**

If you feel able to complete most but not all of the above then do not be put off, just let me know what you can but also cannot do.

Do you remember earlier when we said, 'We are going to visualise this array as being presented in the form `Cells[Y][X]` (as opposed to `Cells[X][Y]`, which would be a tad more intuitive).' Well, this is where we discover the rationale behind this scheme, and also why we decided to think of our array in its 'Opposite Day' configuration.

One of the things we want to be able to do is load our array with an initial 'Seed' configuration. The way I decided to specify this seed is as a 2D array of integers, as shown in Fig.6. Observe that I've specified a Glider (shown as red '1' characters) in the lower left-hand corner. You can observe this Glider in action in a video I just captured: **https://bit.ly/3bMZbGQ**

```
int Seed[NUM_Y][NUM_X] =
{                                   //  Y  |  X   |
    {0,0,0,0,0,0,0,0,0,0,0,0}, //  0  0 <-> 11
    {0,0,0,0,0,0,0,0,0,0,0,0}, //  1  0 <-> 11
    {0,0,0,0,0,0,0,0,0,0,0,0}, //  2  0 <-> 11
    {0,0,0,0,0,0,0,0,0,0,0,0}, //  3  0 <-> 11
    {0,0,0,0,0,0,0,0,0,0,0,0}, //  4  0 <-> 11
    {0,0,0,0,0,0,0,0,0,0,0,0}, //  5  0 <-> 11
    {0,0,0,0,0,0,0,0,0,0,0,0}, //  6  0 <-> 11
    {0,1,0,0,0,0,0,0,0,0,0,0}, //  7  0 <-> 11
    {0,0,1,0,0,0,0,0,0,0,0,0}, //  8  0 <-> 11
    {1,1,1,0,0,0,0,0,0,0,0,0}, //  9  0 <-> 11
    {0,0,0,0,0,0,0,0,0,0,0,0}, // 10  0 <-> 11
    {0,0,0,0,0,0,0,0,0,0,0,0}  // 11  0 <-> 11
};
```

Fig.6. An example seed array.

The way the C/C++ compiler works, when we declare a 2D array, the first index is for the rows (our Y axis, with Y = 0 at the top and Y = 11 at the bottom) and the second index is for the columns (our X axis, with X = 0 on the left and X = 11 on the right).

Now all becomes clear. When we specify a starting pattern in our `Seed[][]` array, we want that pattern to be replicated 'as-is' on the physical array, otherwise we're going to end up spending an inordinate amount of time performing mental gymnastics as we try to convert from one representation to another in our heads (and I fear my gymnastic days are behind me). In the same way that there's no point in barking when you have a dog, there's also no point making your head hurt performing wacky transformations when you have a computer to do them for you.

I think you'll find the rest of the program easy to understand. As you'll see, in addition to our `GetNeoNum()` function, we've declared four other functions. The `InitializeUniverse()` function loads the current generation (Generation 0, in this case) in our `Cells[][]` array with `ALIVE` or `DEAD` values, as defined in our `Seed[][]` array. The `EvaluateNextGeneration()` function scans the current generation to determine the number of live neighbours for each cell, after which it decides what each cell is going to do going forward to the next generation. If a cell is currently alive, the two choices are for it to stay alive or to die; if the cell is currently dead, then the two options are for it to stay dead or to spring into life.

The `UpdateCurrentGeneration()` function takes the results from the `EvaluateNextGeneration()` function and uses them to define the next generation; that is, the new current generation. Finally, the `DisplayCurrentGeneration()` function takes the current generation data and displays it on the physical array.

After initialising the NeoPixels by turning them all off, the `setup()` function calls the `InitializeUniverse()` function followed by the `DisplayCurrentGeneration()` function, after which we pause for a couple of seconds to make sure what we see on the physical array is what we expected to see as specified in our `Seed[][]` array. Next, the `loop()` function cycles around calling the `EvaluateNextGeneration()`, `UpdateCurrentGeneration()`, and `DisplayCurrentGeneration()` functions.

Next time...

In our earlier experiments with the array, we faded from one colour to another. Consider the Glider sequence shown in Fig.2. How might we modify our code to fade from one pattern to the next, as opposed to the 'bang-bang-bang...' approach we are currently using? Similarly, consider the sequence shown in Fig.1. How might we modify our program to (a) display the intermediate (half-generation) steps, (b) use colours to reflect the four cases of staying alive, staying dead, coming alive, and dying, and (c) to do all this using our fading techniques?

In my next column, we will answer these questions, after which we will start to look at a new form of display that – if you are anything like me – will make you squeal in delight. Until then, have a good one!

Solution to GetNeoNum()

The modifications we need to make to our `GetNeoNum()` function to reflect our 'Opposite Day' view of the world are easy-peasy-lemon-squeezy. All we have to do is add the following statement before any of the existing statements (where `MAX_XY` is defined as being 11):

```
yInd = MAX_XY - yInd;
```

Now, if we assume [X,Y] = [0,0], then when we apply these values to our modified function it returns 133, which is the physical number of the pixel in the upper left-hand corner. Hurray Squared!

Cool bean Max Maxfield (Hawaiian shirt, on the right) is emperor of all he surveys at **CliveMaxfield.com** – the go-to site for the latest and greatest in technological geekdom.

Comments or questions? Email Max at: **max@CliveMaxfield.com**

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Make it with Micromite

Phil Boyce – hands on with the mighty PIC-powered, BASIC microcontroller

Part 28: Internet connection with an ESP32 Wi-Fi module – Part 1

Over the next two months, we are going to show you how to connect your *Micromite Keyring Computer* (*MKC*) to the Internet. This is not so you can browse the Internet (you probably have enough devices for that already); instead, it's so we can extract useful data that is available online. If you're not already aware, there is a vast amount of accessible data on the Internet; for example, information about what is on TV and Radio, or data regarding the relative positions of the planets. Accessing and using this data with the *MKC* means it would be a simple task to make an MMBASIC program do some very impressive things.

To put this data retrieval into practice, we will begin with something simple – how to extract the correct time from an Internet time server (often referred to as an NTP server). We will then demonstrate something much more fun – how to extract live weather data for anywhere in the world (thanks to **openweathermap.org**).

To achieve data retrieval, the only hardware we need to attach to the *MKC* is some form of module that enables connection to the Internet. This may sound like a complex electronics project, but by using a dedicated Wi-Fi module built specifically for this task (and assuming you have access to a Wi-Fi network/router), then it's actually quite easy. Thankfully, there are several devices available that allow us to achieve this, and here we have chosen a popular (and low-cost) ESP Wi-Fi module.

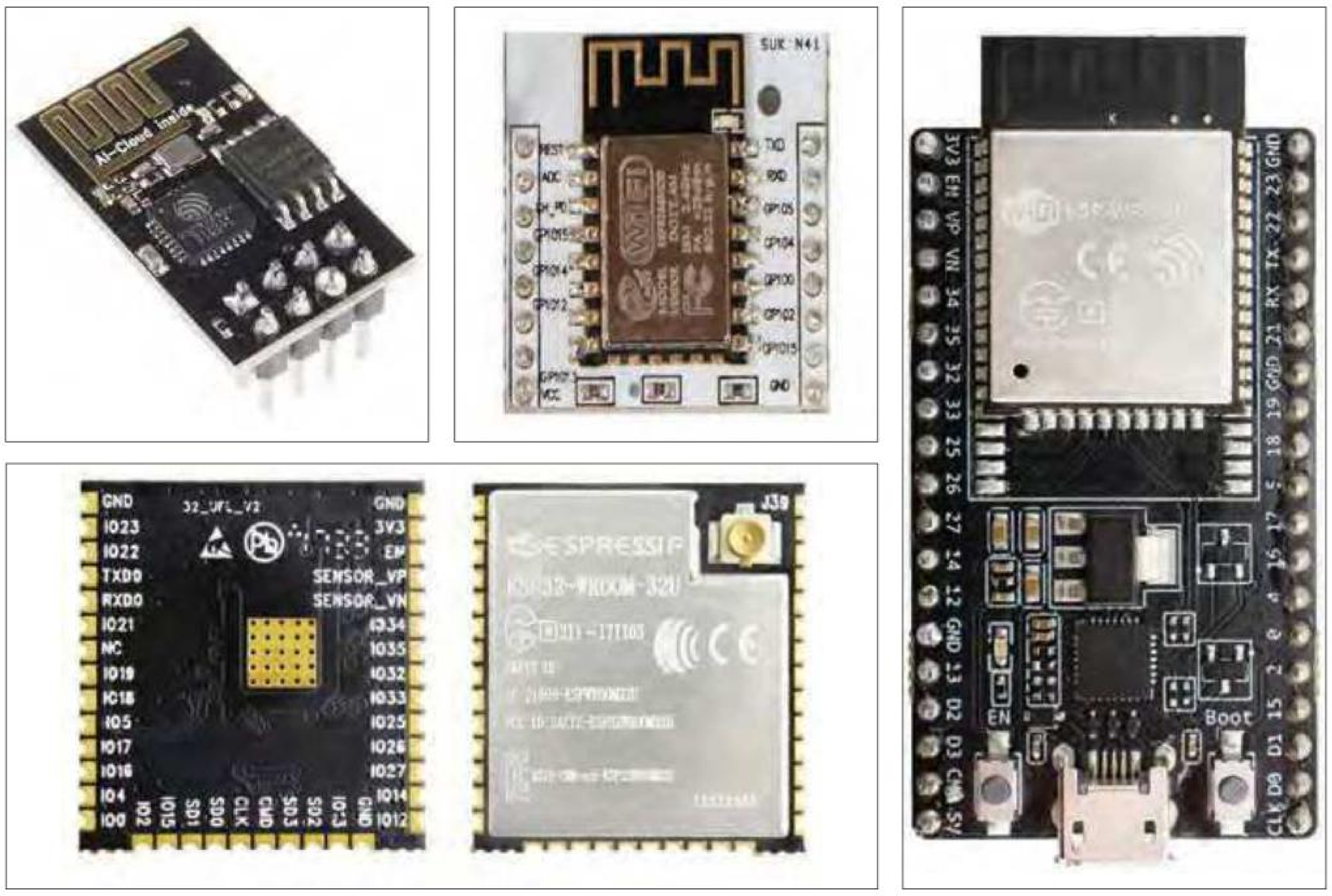


Fig.1. Many different ESP modules are available. Shown here are (top left) ESP8266-01, (top centre) ESP8266-12e, (bottom left) ESP32-core back/front, and (right) ESP32 WROOM development board.

ESP Wi-Fi modules

A quick online search will reveal that there are two main types of ESP Wi-Fi module available: the ESP8266 and the ESP32. The ESP8266 was the first to appear back in 2014, and this was followed two years later by the ESP32. The most noticeable difference between these two is that the ESP32 provides Bluetooth connectivity as well as Wi-Fi. However, the ESP32 also has additional Wi-Fi capability, along with improved Wi-Fi connectivity over the ESP8266. An important point to note here is that the ESP8266 and the ESP32 Wi-Fi modules both come in several different versions (see Fig.1), with each core module being manufactured by the Chinese company Espressif. There are numerous suppliers selling various ESP modules, with many suppliers even offering their own custom-built development board(s) incorporating a specific ESP module.

Micromite code

The code in this article is available for download from the *PE* website.

Because the ESP modules have been available for several years, you may have already used one in a previous project, but if not, simply consider an ESP Wi-Fi module as a small PCB containing two main elements: a microcontroller and a Wi-Fi transceiver.

The firmware that is loaded into the ESP's microcontroller not only makes it possible to access some of the microcontroller's I/O pins, but also enables the ESP to connect wirelessly to the 'outside-world'. This could mean connecting to another ESP module (effectively creating two ESP microcontrollers that are wirelessly connected to each other) or what is much more common, allowing wireless connection to the Internet – what we will be doing.

There are three main benefits of using ESP Wi-Fi modules: they are cheap (from below £5); readily available online; and the software in the ESP's microcontroller can be reprogrammed to provide the required functionality.

The benefits of low-cost and ready availability are obvious; however,

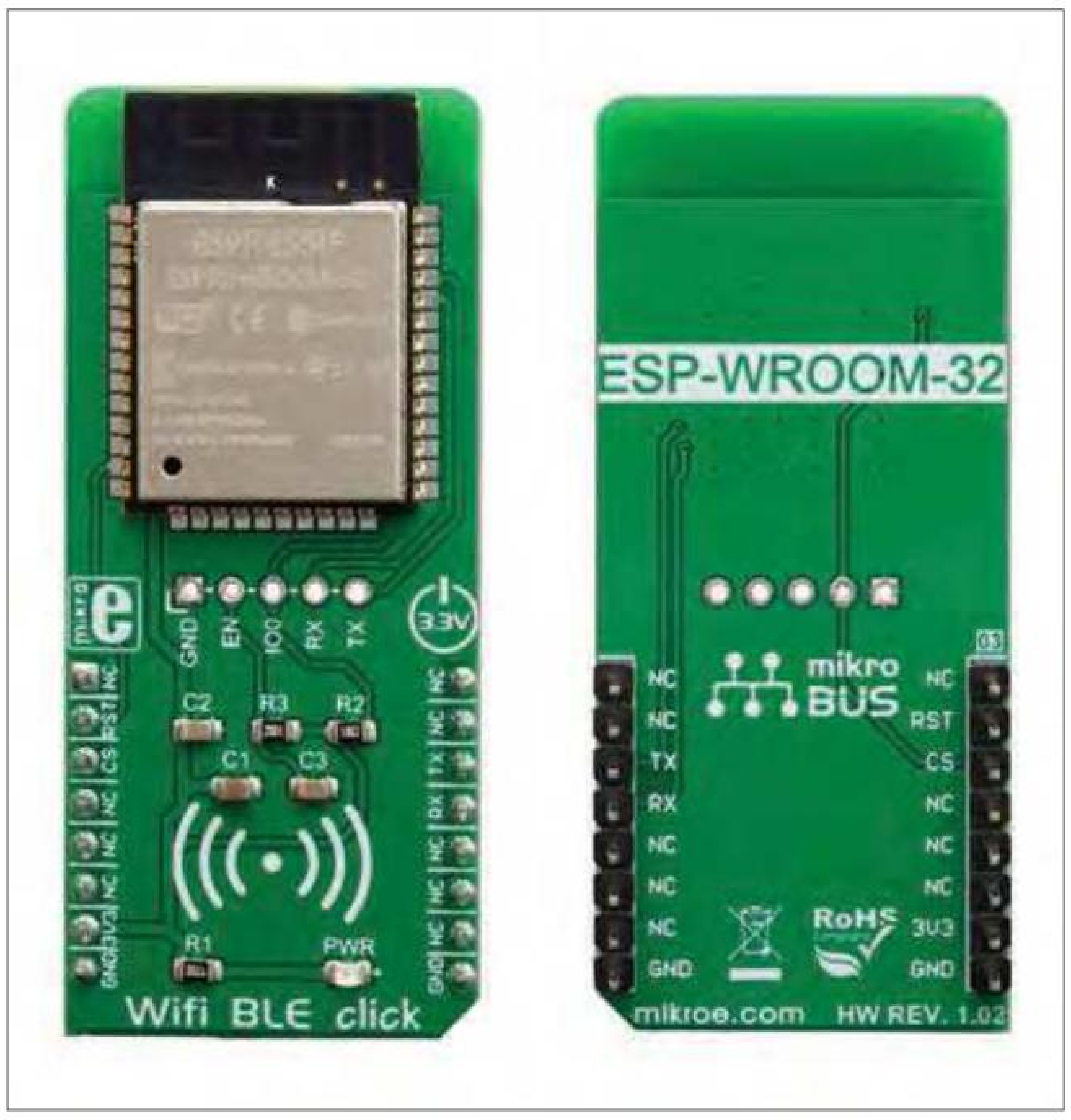


Fig.2. The MIKROE-3542 is a well-built ESP32 module from MikroElektronika; it comes pre-loaded with firmware that accepts a full set of AT commands.

buyer-beware, as these two can be a problem – unfortunately, (very poor) copies exist. I have received some that look like they were soldered by a total novice, and other modules that had badly placed components, and even on a few occasions components were missing altogether. My advice is to buy a branded module – this has always proved to be safe and reliable.

ESP firmware and software

The ESP's software complexity is often the reason why many people are put off using an ESP module in the first place (me included!). To explain this further, think for a moment about the Micromite. MMBASIC is the firmware that is pre-installed inside the Micromite. It permanently resides in memory (or until you wish to upgrade it with a dedicated programmer such as a PICkit or a MicroBridge). It is the firmware that enables the Micromite to understand typed commands and hence make it do something useful. For example, you may write some code (your program), and `RUN` it to see the end result. You can `EDIT` the program code at any point, but that doesn't affect the firmware in any way. Typing `LIST` allows you to see the code; typing `NEW` will remove the program code from the Micromite. All of these commands work with just the program code and leave the firmware untouched. Even though the program code also remains in memory when the power is removed, it is editable via commands, but the firmware is truly fixed.

Now back to the ESP, it too has firmware and program code. It is very important here to understand that there are many different versions of ESP firmware; from factory-versions supplied by Espressif, to custom-built versions of firmware written by suppliers and developers. Put simply, this means that if you were to buy two ESP modules of the same hardware version, it does not necessarily mean they will both have the same firmware installed. So why is this important to understand? – remember, it is the firmware that determines the commands, features, and functionality available to the end user.

Now let's quickly talk about the ESP program code. A typical scenario is where an end-user uses a development environment designed for the Arduino. This allows the program code to be written on a computer, compiled, and then uploaded to the ESP module for testing. This process is then repeated until the code performs as required. For many people, this is simply a barrier as they don't understand the programming language used.

The ideal ESP module

What we really want is a well-built ESP module with a known version of pre-loaded firmware, which in turn has a complete set of commands (that are simple to use) and that provide full functionality of all features. And if it were possible to send the commands (and get responses) via a simple hardware interface (such as a serial UART), then this would mean we could totally bypass the need to write, compile and upload any complex software into the ESP's microcontroller. Instead, we could simply control the ESP module externally.

This simple concept would allow us to use a Micromite as the external controller, connected directly to the ESP via just a two-wire serial link. More importantly, we can then easily send commands from within our MMBASIC program code, and likewise, receive responses too.

Thankfully, ESP modules do have a serial connection allowing external control; so it was really just a matter of finding a suitable firmware. Several firmware versions claim to support the ability to accept a simple set of commands. However, in practice, only a few modules seem to support all the commands required to reliably talk to various online servers. So, after experimenting with several different ESP modules from various suppliers that claim to offer the above, we settled on an ESP Click module made by MikroElektronika; or to be more precise, the MikroElektronika Wi-Fi BLE Click ESP32-WROOM-32 Bluetooth Wi-Fi 2.4GHz MIKROE-3542 (see Fig.2).

A question you may be asking is why we decided to use a Click module based on an ESP32 over one that uses a ESP8266. This comes down to a commercial project I was working on in which the requirement was to be able to reliably send data to a database that resided in the Cloud. It is too complex to explain fully, but in summary, the data was effectively being pushed to a secure web address beginning HTTPS (as opposed to HTTP). It turned out that unless the ESP8266 is reprogrammed with a custom-built version of firmware, it will only allow data to be sent to HTTP. Reprogramming the firmware resulted in several bricked ESP modules, so I gave up with that approach and got the ESP32 module working at the first attempt. It was then just a matter of looking for a readily available branded module that would make it far easier for *PE* readers to use – hence we're taking the Mikroe-3542 route.

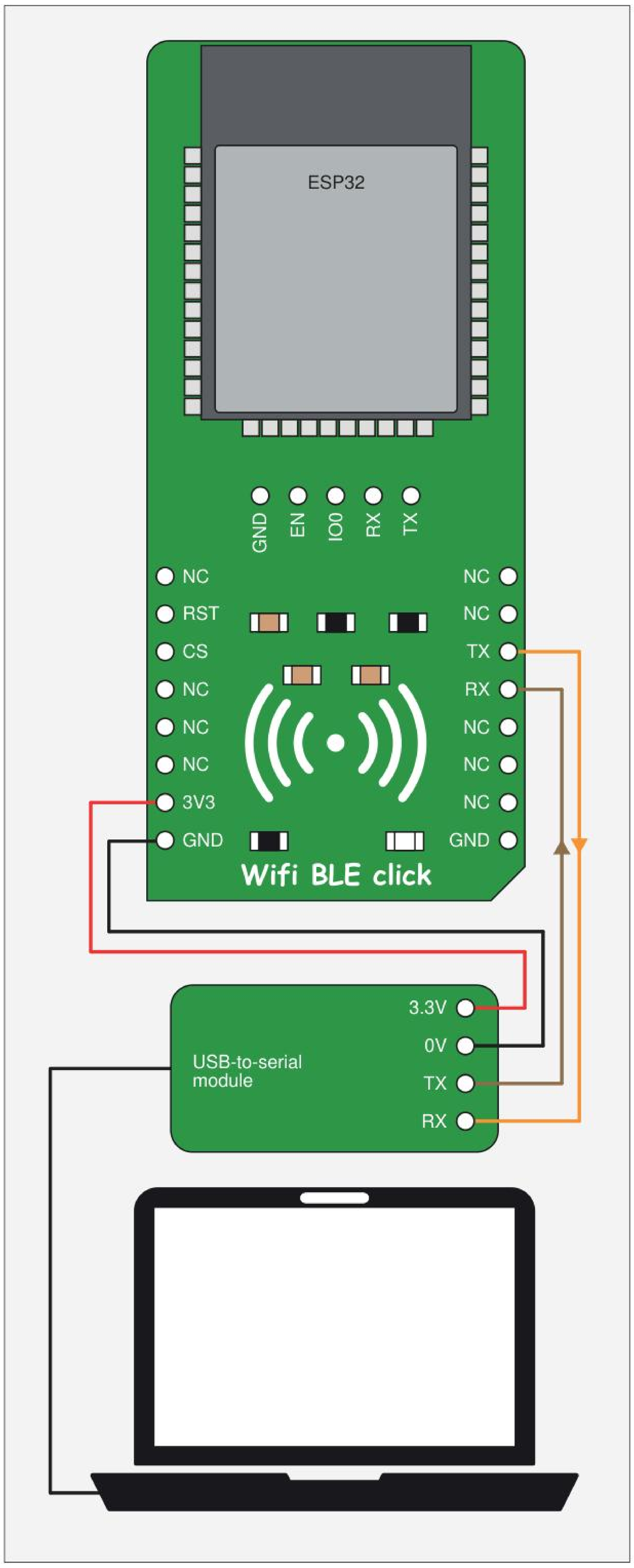
Can I use an ESP8266?

As an aside, it is worth noting that the ESP8266 module can be used as an alternative to the ESP32 if you have one lying around, but it will need to have a version of firmware that accepts the AT command set. I cannot guarantee that all the AT commands used in this article will be available to you as that depends on the firmware, as clearly outlined previously – but at least you can begin to experiment, and certain things may work. So, to be clear, the rest of this article will assume you are using the ESP32 module.

AT commands

You will likely come across AT commands whenever you use a communications module (ie, a modem). In fact, we discussed them very briefly back in *Part 14* of this series (*PE*, March 2020) when we were using a Bluetooth module. The term 'AT' comes from the first two letters of the word 'attention'. It can be regarded as one device saying to another, 'Hey, I'm about to talk to you!'. In the early days of modem communication, AT was used to signify that what followed was a communication command, and it has pretty much been adopted ever since. Hence, every AT command begins with the letters 'AT' (or 'at'), an example being AT+RST. The command is only sent to the module after sending a 'Carriage Return', ie, pressing the Enter key if sent from a computer. The communications module will then act upon the command it receives and send back an appropriate response. The simplest form of response is 'OK' and some commands will send just this. However, other commands will return one (or more) line(s) of data, followed with an 'OK' at the end.

One point to note here is that it is good practice to use commands in upper case because this guarantees they will work correctly (I have several modules that do not respond to some commands when sent in lower case).



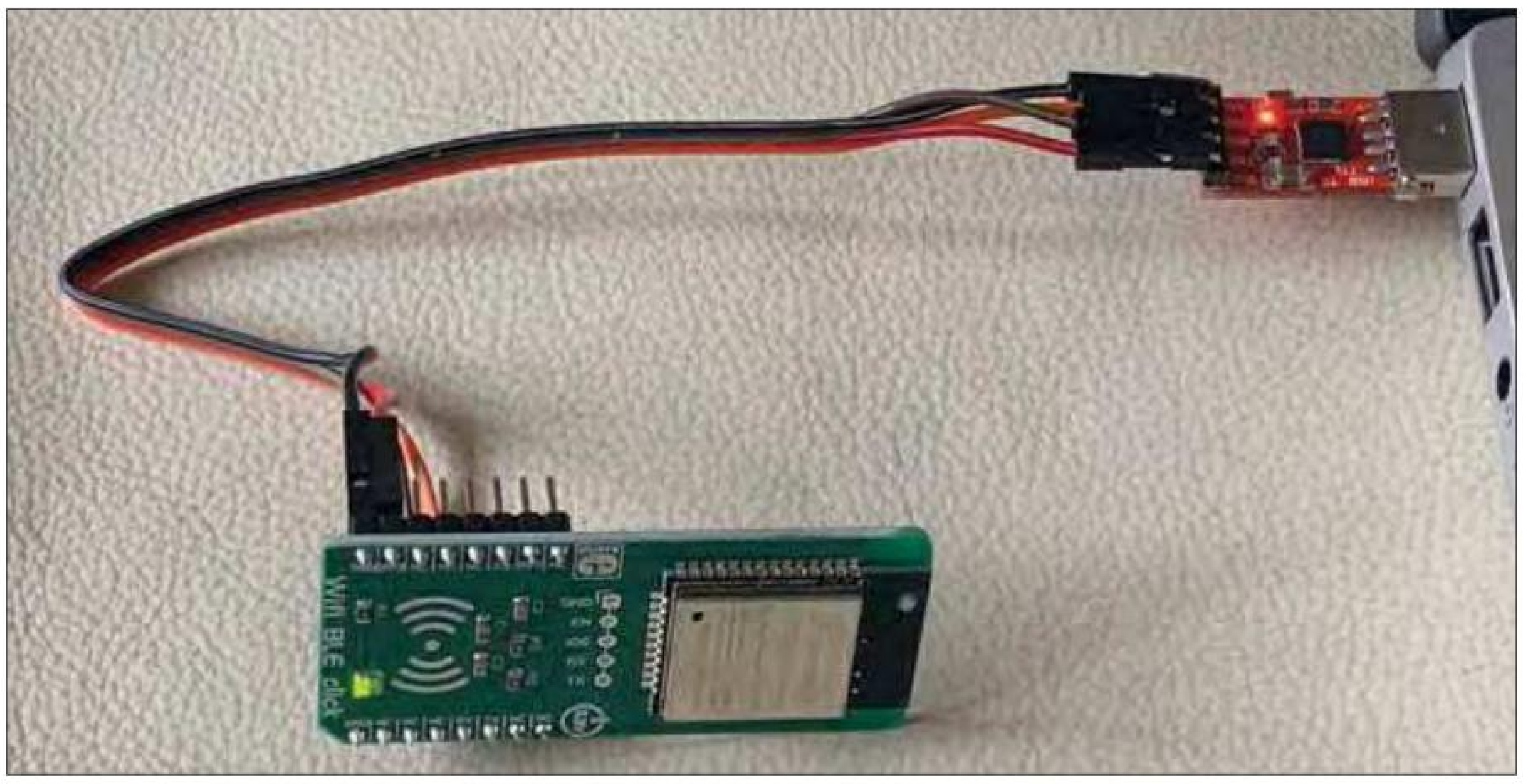


Fig.3. To test the ESP module, we connect it directly to a USB-to-serial module: a) (left) just four connections required; b) (right) no need for a breadboard, simply use jumper cables (female/female shown here).

We are not going to go into the fine detail of the ESP's AT command set here, but if you're interested, useful documents can be found at the manufacturer's website: **http://bit.ly/pe-may21-exp**

Connecting the ESP32 to the MKC

Now that we have chosen our ESP module, we'll start with a simple test. This will prove that we have a working ESP module, that it is powered correctly, and that the ESP firmware can indeed respond to commands externally sent to it. For this test you will need a USB-to-serial module such as a CP2102, or one based on an FTDI chip. You will likely have one already, but if not, then it is well worth getting a few to tuck in the draw as they always come in handy (simply check online, and you'll find many available for around £1 plus delivery).

For this test, there are only four links required, as shown in Fig.3a. I tend to use male/female jumper wires to hook the ESP module to the USB-to-serial module rather than using a breadboard (see Fig.3b). One word of warning; the ESP32 Click module requires 3.3V, so take care when attaching the +V link (5V will damage the ESP module). With 3.3V and 0V connected, and the USB-to-serial module plugged into your computer, you should see the power LED illuminate on the ESP module.

Once all four links are connected, launch your terminal application (eg, TeraTerm) and check that your settings match those in Fig.4a and Fig.4b: set the baud rate (115200) and receive/transmit characters (LF/CR+LF).

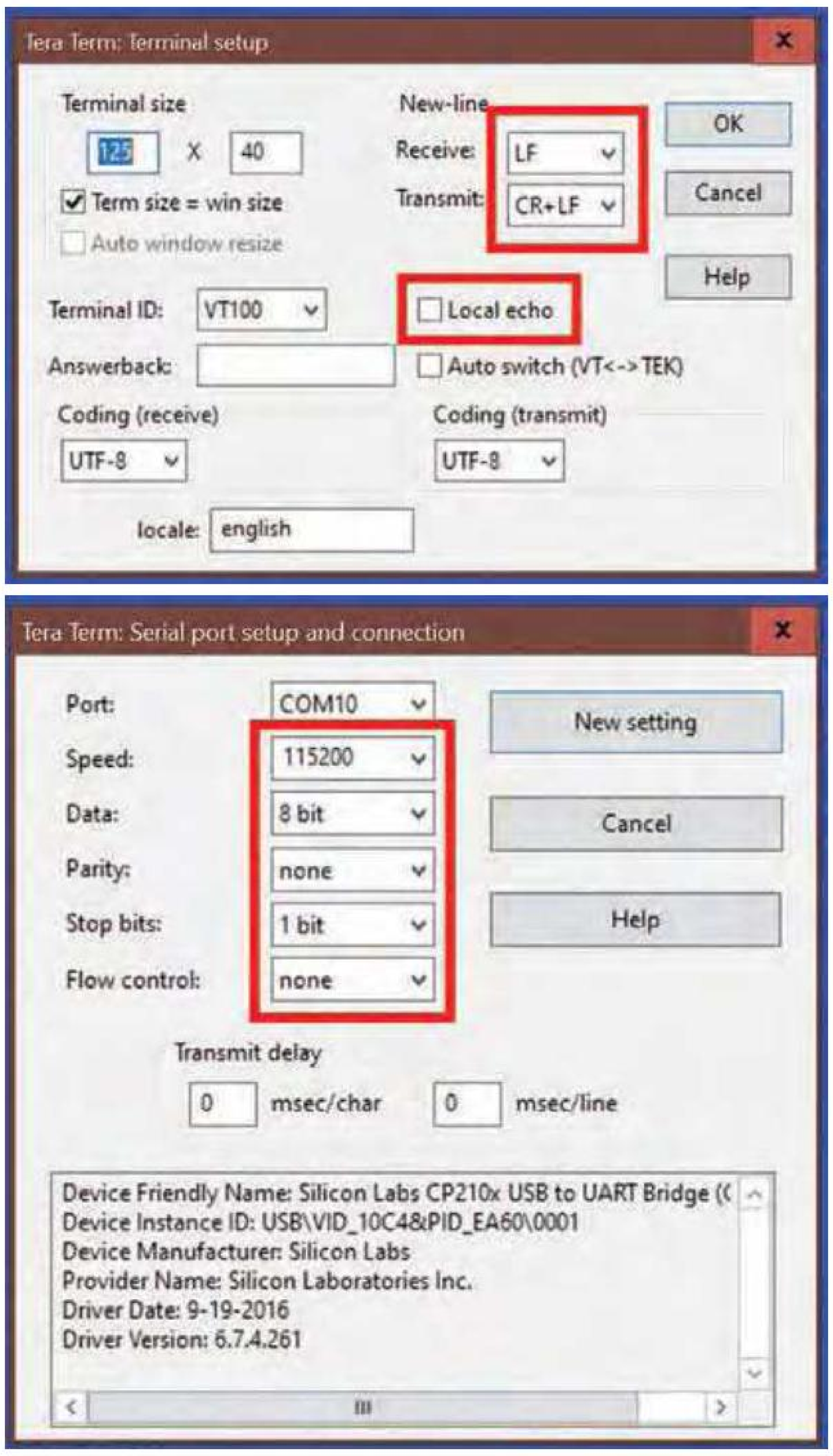
Next, ensure the caps Lock is turned on (or hold down the shift key), and type `AT` followed by pressing `Enter`. As you type, you should see `AT` appear on the screen – if not, then check you have the Tx/Rx connected correctly, and that you have the correct baud rate set in your terminal application.

If everything was set up correctly you should see `OK` on the screen. If so, continue with another command: `AT+GMR`, which checks the version number of your ESP module. Fig.5 shows a screenshot of my result from sending these two commands to the ESP32.

What's the time?

Now that we have confirmed that the ESP module is working, we can disconnect it from the USB-to-serial module and connect it directly to the *MKC*. This will then allow us to start using the *MKC* to externally control the ESP module; our first demonstration is to fetch the date and time from an Internet-based time server.

Refer to Fig.6 to see the five connections required. In addition to the four links we used in the test above, we will also connect the CS pin on the ESP module to an I/O pin on the *MKC* (which is configured as an output). When the CS pin is at a high logic level, the ESP functions as normal, but taking the CS pin low will result in



Tera Term: Terminal setup

Terminal size: 125 x 40

☑ Term size = win size

☐ Auto window resize

New-line

Receive: LF

Transmit: CR+LF

Terminal ID: VT100

☐ Local echo

Answerback:

☐ Auto switch (VT<->TEK)

Coding (receive): UTF-8

Coding (transmit): UTF-8

locale: english

Tera Term: Serial port setup and connection

Port: COM10

Speed: 115200

Data: 8 bit

Parity: none

Stop bits: 1 bit

Flow control: none

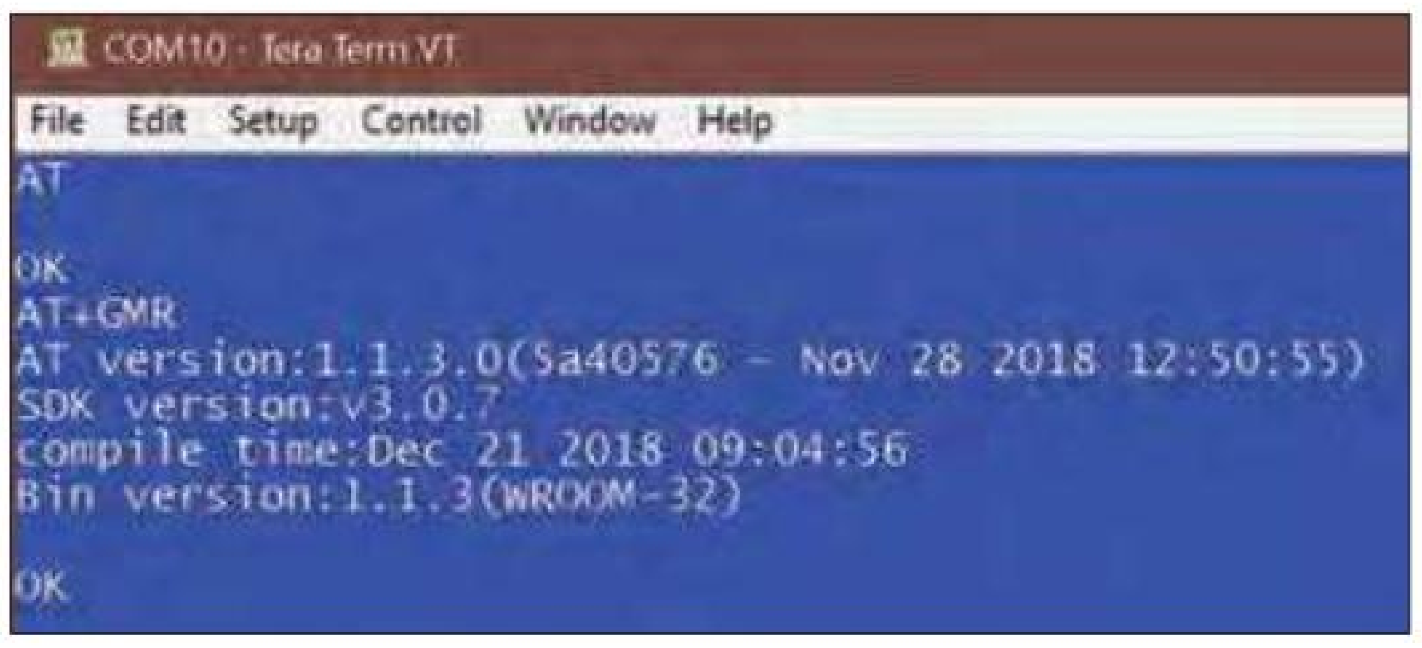
Transmit delay

0 msec/char

0 msec/line

Device Friendly Name: Silicon Labs CP210x USB to UART Bridge (C
Device Instance ID: USB\VID_10C4&PID_EA60\0001
Device Manufacturer: Silicon Labs
Provider Name: Silicon Laboratories Inc.
Driver Date: 9-19-2016
Driver Version: 6.7.4.261

Fig.4. Ensure your terminal application settings match these parameters. Shown here are screenshots from using TeraTerm: a) (top) **Setup/Terminal…** settings; b) (bottom) **Setup/Serial port…** settings.



```
AT

OK
AT+GMR
AT version:1.1.3.0(5a40576 - Nov 28 2018 12:50:55)
SDK version:v3.0.7
compile time:Dec 21 2018 09:04:56
Bin version:1.1.3(WROOM-32)

OK
```

Fig.5. After typing both test commands (`AT` and `AT+GMR`), you should see something like that shown here.

the ESP module being reset. So go ahead and make these five connections, and then perform a quick visual check to ensure that everything is correct before switching on.

Next, download the file **NTP_TimeDemo.txt** from the May 2021 page of the *PE* website and load it into the *MKC*. Before you run the program you will need to `EDIT` the first two lines of code for the ESP module to successfully connect to your wireless network. Simply enter your wireless network name (`SSID$`), and password (`PWD$`). Once this is done, `RUN` the program and you should see (on your terminal screen) the activity of the ESP module connecting to your network, fetching the data, and then displaying the date and time that was received from the NTP server (see Fig.7a). Depending on your location in the world, you may also need to edit lines 3-5 of the program to match your relevant NTP server (a quick Google search will highlight what these are – and up to three NTP addresses can be entered). The first time the program is run, the ESP will need to load your network log in parameters (the `SSID$` and `PWD$`). On subsequent occasions when you `RUN` the program, the ESP will already be connected to your network so the screen activity will look slightly different (see Fig.7b).

Line 6 of the code (`Debug=1`) can be changed to `Debug=0`, which will suppress all the AT command activity from being displayed on the terminal screen. Make this change and run the program again; you should now just see the date and time (see Fig.7c).

So how does this all work? Well, that will have to wait for next month, but for those of you who want to explore things further, do take a look at the code, in particular the two ESP commands: `AT+CIPSNTPCFG and AT+CIPSNTPTIME?`

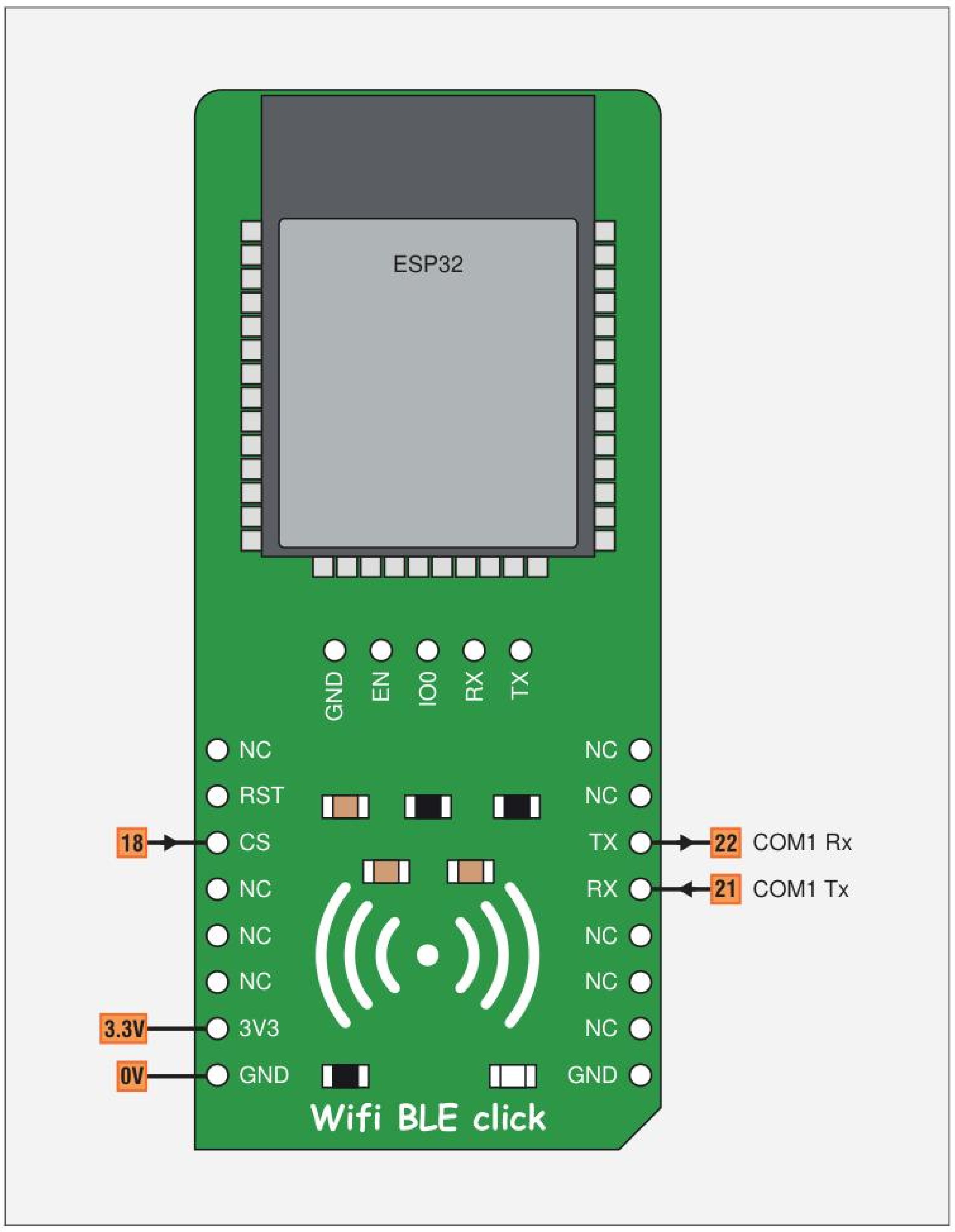
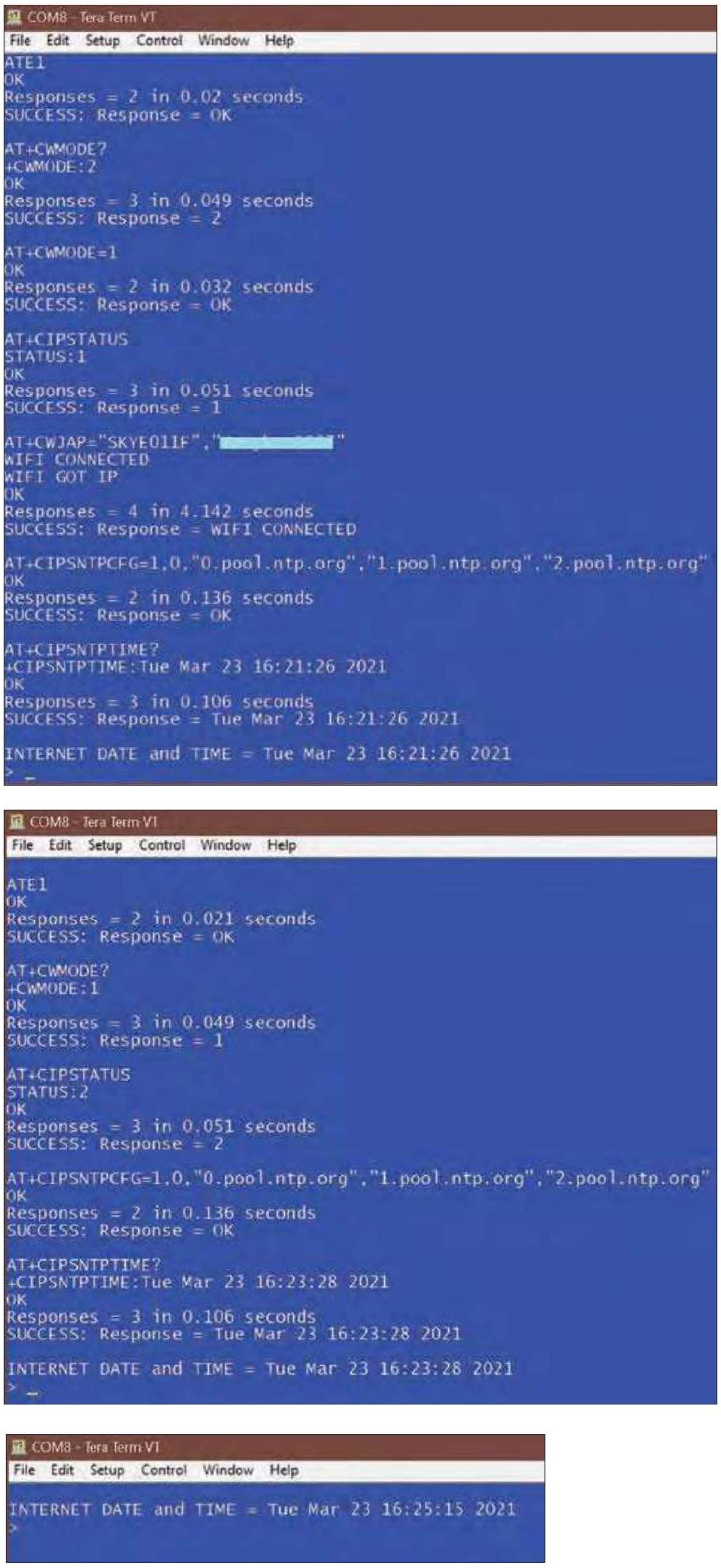


Fig.6. Only five links are required to connect the ESP32 module to your *MKC*.



```
ATE1
OK
Responses = 2 in 0.02 seconds
SUCCESS: Response = OK

AT+CWMODE?
+CWMODE:2
OK
Responses = 3 in 0.049 seconds
SUCCESS: Response = 2

AT+CWMODE=1
OK
Responses = 2 in 0.032 seconds
SUCCESS: Response = OK

AT+CIPSTATUS
STATUS:1
OK
Responses = 3 in 0.051 seconds
SUCCESS: Response = 1

AT+CWJAP="SKYE011F","[redacted]"
WIFI CONNECTED
WIFI GOT IP
OK
Responses = 4 in 4.142 seconds
SUCCESS: Response = WIFI CONNECTED

AT+CIPSNTPCFG=1,0,"0.pool.ntp.org","1.pool.ntp.org","2.pool.ntp.org"
OK
Responses = 2 in 0.136 seconds
SUCCESS: Response = OK

AT+CIPSNTPTIME?
+CIPSNTPTIME:Tue Mar 23 16:21:26 2021
OK
Responses = 3 in 0.106 seconds
SUCCESS: Response = Tue Mar 23 16:21:26 2021

INTERNET DATE and TIME = Tue Mar 23 16:21:26 2021
> _
```

```

ATE1
OK
Responses = 2 in 0.021 seconds
SUCCESS: Response = OK

AT+CWMODE?
+CWMODE:1
OK
Responses = 3 in 0.049 seconds
SUCCESS: Response = 1

AT+CIPSTATUS
STATUS:2
OK
Responses = 3 in 0.051 seconds
SUCCESS: Response = 2

AT+CIPSNTPCFG=1,0,"0.pool.ntp.org","1.pool.ntp.org","2.pool.ntp.org"
OK
Responses = 2 in 0.136 seconds
SUCCESS: Response = OK

AT+CIPSNTPTIME?
+CIPSNTPTIME:Tue Mar 23 16:23:28 2021
OK
Responses = 3 in 0.106 seconds
SUCCESS: Response = Tue Mar 23 16:23:28 2021

INTERNET DATE and TIME = Tue Mar 23 16:23:28 2021
> _
```

```
INTERNET DATE and TIME = Tue Mar 23 16:25:15 2021
>
```

Fig.7. Top to bottom: a) the first time you run the program, the ESP32 will be configured with your wireless network parameters; b) once set up, running the program again will get the NTP data quicker; c) the commands sent to the ESP (and response back) can be suppressed by setting `Debug=0`.

Next month

Now that we have our ESP module connected to the *MKC* and have been able to demonstrate that it is possible to extract the date and time from an NTP server, we will work through the program code and explain how it works. Then we will show you how to extract real-time weather data for any location in the world. Until then, have FUN!

Questions? Please email Phil at:
contactus@micromite.org

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PIC n' Mix

Mike Hibbett's column for PIC project enlightenment and related topics

Part 5: PIC18F Development Board

In the previous article of this series (March 2021) we covered the PCB design and assembly of our PIC18F development board. We ran some initial 'smoke tests' to see whether revision 1 of the PCB was fit for purpose – and it was… more or less!

A few minor issues were found during initial testing, and a couple more in the weeks that followed during initial use of the board. Some of the resulting changes are to minimise component count (isolating the copper underneath IC1, to avoid needing a TO220 insulation shim when screwing the regulator down) and the addition of solder pads for two previously unused op amps. We had also missed a few useful silkscreen labels, which were easily added.

The low-value capacitors had been placed with a package footprint intended for a 0.1-inch pitch radial part, but to increase the flexibility for using the alternative 0.2-inch pitch packages, we have changed the PCB footprint to a 'combo' package, that provides an extra pad at the alternate spacing. It's surprisingly difficult to find 12pF capacitors (used by the low-frequency real-time clock oscillator) in a 0.1-inch pitch these days. We do miss Maplin!

PCB revision

The final PCB layout can be seen in Fig.1. The schematic has been updated slightly to re-order some of the header labels, but the addition of the two previously unused op amps had already been captured in the schematic published in the previous article (drawings being quicker to update than physical PCBs. The other changes discussed are PCB related rather than schematic.) Fig.2 shows the parts of the schematic that have changed – we will reprint the full schematic in the next article just in case there are any further changes as we prepare the PCB for manufacturer. The bare PCB will be available to order when the next article in this series is published in the July issue. So, you have plenty of time to order components.

The parts list is shown in Table 1. Notice how this has been split into 'Essential', those components required for basic operation, 'Recommended', and 'Optional'. The optional components are ones that will be used in some future article, or your own designs. Sourcing components can be a challenge these days with the demise of high street vendors like Radio Shack or Maplin, and delivery charges from the likes of Farnell or RS Components can be excessive for the low-cost of the parts you will be ordering. Do check our own component suppliers advertising in the magazine, and also consider eBay and even Amazon – it can be surprising where components or PCB assemblies pop up. In particular, we make use of many 0.1-inch pitch header pin strips. These can be purchased cheaply on eBay, and also Amazon. While the bulk of the items can be ordered through Digikey, it can be worth looking for the same manufacturer parts through other suppliers, such as RS Components or Farnell. Do watch out for delivery fees – it may be worth buying several sets of components or other items to avail yourself of free delivery for orders above purchase cost thresholds.

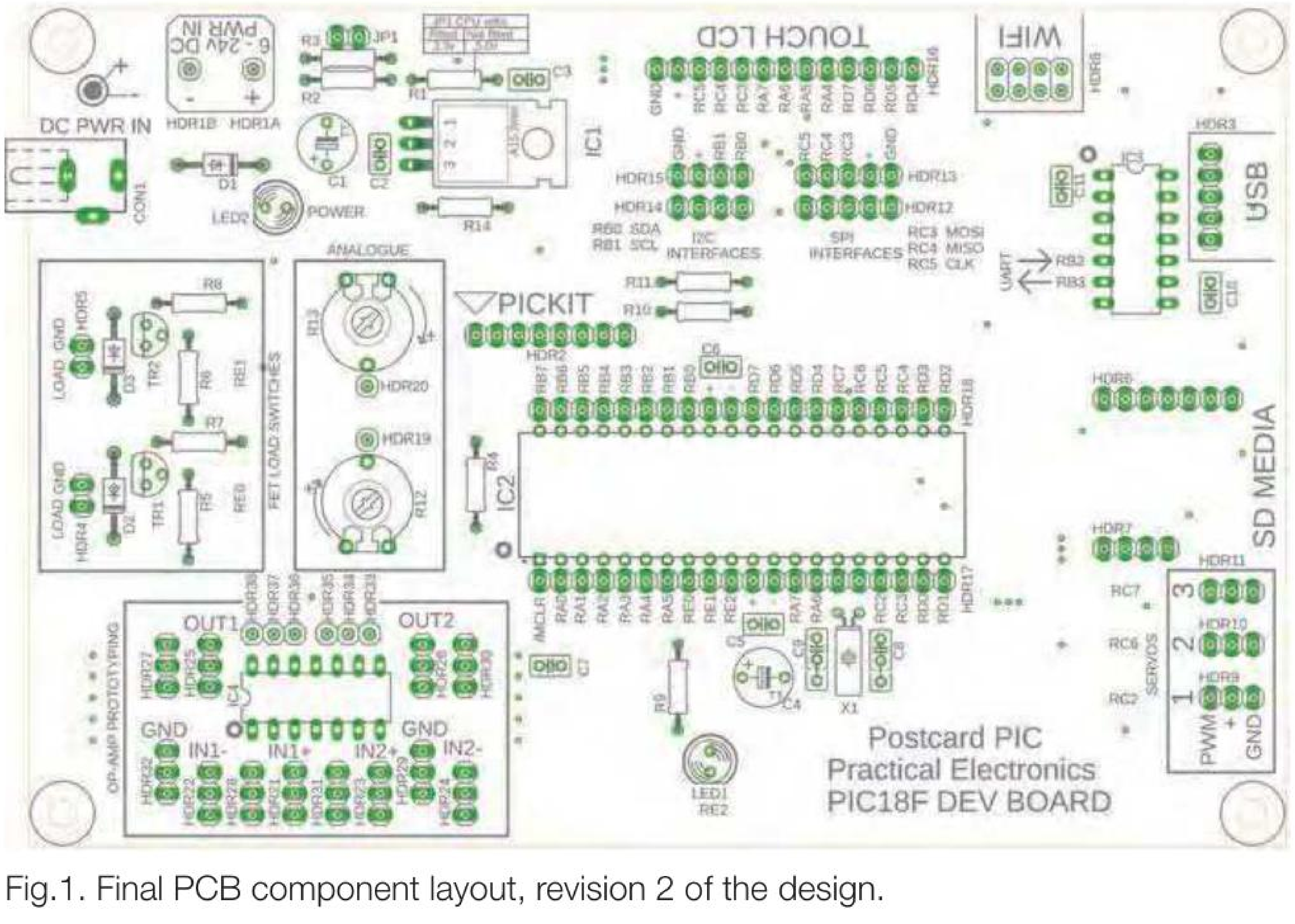

DC PWR IN
6 - 24V DC PWR IN
HDR1B
HDR1A
CON1
D1
LED2
POWER
C1
C2
R1
R2
R3
JP1
C3
IC1
R14
ANALOGUE
R13
R12
HDR20
HDR19
R8
R7
R6
R5
TR1
TR2
D2
D3
LOAD GND
HDR4
HDR5
RE0
RE1
FET LOAD SWITCHES
PICKIT
HDR2
R11
R10
R4
IC2
C6
TOUCH LCD
HDR16
WIFI
HDR6
HDR15
HDR14
HDR13
HDR12
RB0 SDA
RB1 SCL
I2C INTERFACES
SPI INTERFACES
RC3 MOSI
RC4 MISO
RC5 CLK
UART
RB2
RB3
IC3
C11
C10
HDR3
USB
HDR8
SD MEDIA
HDR7
HDR18
HDR17
HDR11
HDR10
HDR9
RC7
RC6
RC2
SERVOS
3
2
1
PWM
+
GND
OP-AMP PROTOTYPING
OUT1
OUT2
IC4
GND
IN1-
IN1+
IN2+
IN2-
C7
C5
C4
T1
C8
C9
X1
R9
LED1
RE2
Postcard PIC
Practical Electronics
PIC18F DEV BOARD

Fig.1. Final PCB component layout, revision 2 of the design.

Generally useful things

Besides the components listed in Table 1, there are some items that you will find useful to have at hand. De-soldering braid, to help with cleaning up solder shorts. Also, hook-up wires, in all three styles (male-female, female-female, male-male.) These are very cheap on eBay and it's well worth buying lots of these, as they are cheap and seem to disappear quickly in our lab. Isopropyl alcohol (from a chemist,) cotton buds and a toothbrush are useful for cleaning soldering flux from boards – which not only makes your board look nicer, but also will help you spot any soldering splashes or dry joints.

The PCB will be available for purchase, along with details for ordering in the next *PIC n'Mix* article. This month, while we wait for PCBs to arrive, we will proceed with the software setup.

Setting up the IDE

As many of you will be aware, Microchip produce their own integrated development environment for developing

Table 1: *PIC18F Development Board* components and suppliers.

Circuit ref	No	Description	Supplier	Part number
Essential				
PCB	1	Bare PCB	PE	pic18f-dev-pcb
C2,C5,C6,C7,C11	5	0.1µF ceramic, 0.1-inch pitch	Digikey	BC1148CT-ND
C1,C4	2	10µF Tant, 0.2-inch pitch	Digikey	478-7368-1-ND
C8,C9	2	12pf ceramic, 0.1-inch pitch	Digikey	BC1002CT-ND
C3,C10	2	1µF ceramic, 0.1-inch pitch	Digikey	445-173261-1-ND
R1,R5,R6,R9,R14	5	240Ω 1/4W	Digikey	240QBK-ND
R2	1	390Ω 1/4W	Digikey	CF14JT390RCT-ND
R3	1	330Ω 1/4W	Digikey	CF14JT330RCT-ND
R4,R10,R11	3	4.7kΩ 1/4W	Digikey	A105934CT-ND
R7,R8	2	1MΩ 1/4W	Digikey	CF18JT1M00CT-ND
R12,R13	2	220kΩ Trimpot	Digikey	1993-1085-ND
D1,D2,D3	3	1N4001	Digikey	1N4001RLGOSCT-ND
X1	1	32.768kHz, 12pF loading	Digikey	2151-R26-32.768-12.5-ND
LED1	1	Green 5mm LED	Digikey	C503B-GCN-CY0C0792CT-ND
LED2	1	Red 5mm LED	Digikey	C503B-RAN-CZ0C0AA2CT-ND
TR1,TR2	2	2N2106 FET	Digikey	TN2106N3-G-ND
IC1	1	LM317T TO220 regulator	Digikey	497-1575-5-ND
IC2	1	PIC18F47K42-I/P	Digikey	PIC18F47K42-I/P-ND
IC3	1	MCP2221A DIL14	Digikey	MCP2221A-I/P-ND
IC4	1	MCP604P DIL14	Digikey	MCP604-I/P-ND
JP1	1	0.1-inch header jumper	Digikey	609-6251-ND
	1	7 way 0.1-inch socket header	Digikey	SAM1209-07-ND
	1	4 way 0.1-inch socket header	Digikey	SAM1209-04-ND
	1	5 way 0.1-inch socket header	Digikey	SAM1209-05-ND
	1	2×4 0.1-inch socket header	Digikey	SAM1204-04-ND
HDRs	3	0.1-inch header strip, 40 long	eBay	eg, eBay 192345923109
Recommended				
CON1	1	DC barrel jack	Digikey	3185-FC681465-ND
	1	40-pin DIL socket	Digikey	2057-ICM-640-1-GT-HT-ND
	2	14-pin DIL socket	Digikey	ED3014-ND
	4	Adhesive rubber feet	Digikey	2042-1007-ND
Optional				
Wi-Fi module	1	Wi-Fi module	various	eg, http://bit.ly/pe-may21-ESP8266
USB connector	1	USB connector	Pololu	www.pololu.com/product/2586
SD-Media socket	1	SD-Media socket	Pololu	www.pololu.com/product/2597

software using their processors. This is not the only tool available, and a completely open-source compiler is available, called SDCC. We've stuck with Microchip tools over the years (25 and counting) and found them reliable and continuously in development. The tools we will use are free of charge – you can pay a large sum for the professional version of the compiler, but unless you are a commercial developer you are missing nothing using the free tools. The paid-for version has additional optimisations available (resulting in slightly smaller programs, and slightly faster run time) but you will not notice the difference. The PIC18F47K42 has more than enough code space for our needs, and at 64MHz clock speed it is more than fast enough to run our programs.

There is one downside to the software tools being updated frequently – you may find yourself following these instructions when a newer version of the tools have been released, and you may find the step-by-step instructions are not quite right for the newer version. To help avoid this, we are providing instructions for installing the latest tools, as of March 2021. We recommend that you install the same version of the software tools, which will still be available for download from the Microchip site even if they have updated the version. Also, as the PIC18F47K42 is a mature processor, it is unlikely that a new version of software will introduces any essential features for our processor. You can, of course, update to a new version at a later date.

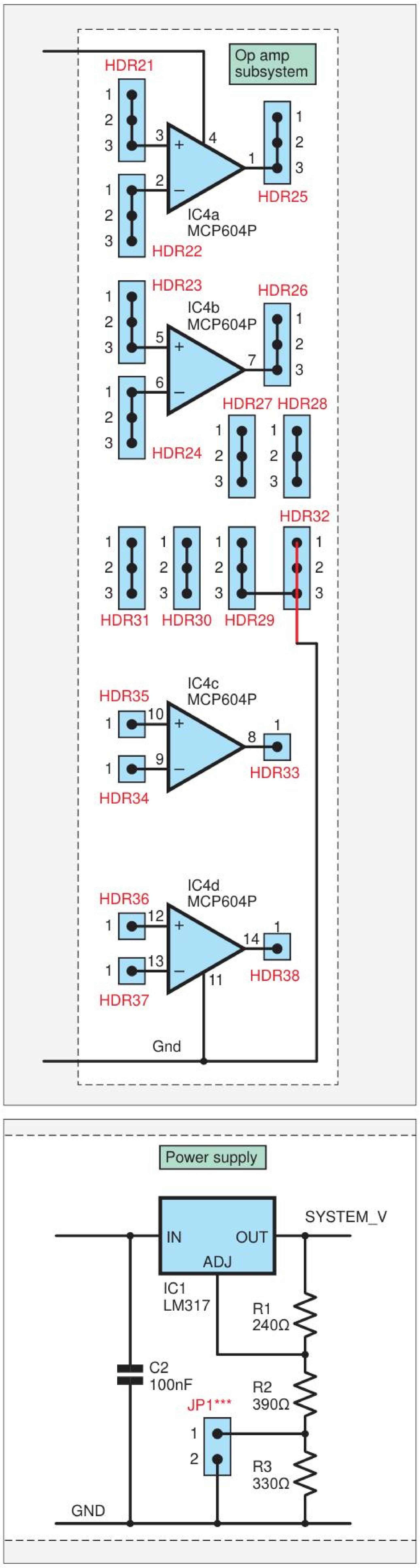
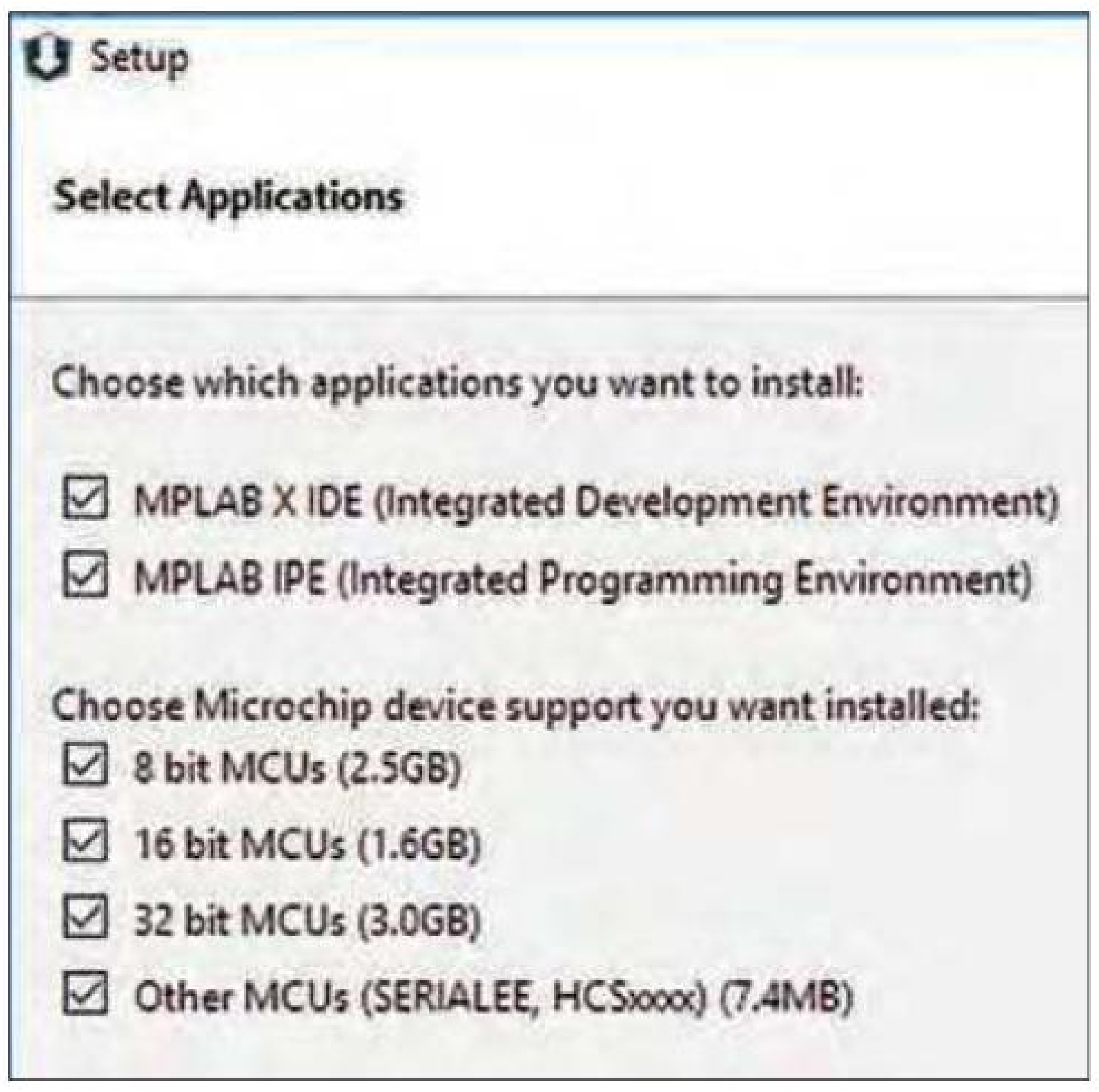


Fig.2. Revised sections of the *PIC18F Development Board's* schematic – changes from the March 2021 version marked in red.

To minimise the likelihood of unexpected software installation issues, we are starting with a completely fresh



Setup

Select Applications

Choose which applications you want to install:

☑ MPLAB X IDE (Integrated Development Environment)
☑ MPLAB IPE (Integrated Programming Environment)

Choose Microchip device support you want installed:

☑ 8 bit MCUs (2.5GB)
☑ 16 bit MCUs (1.6GB)
☑ 32 bit MCUs (3.0GB)
☑ Other MCUs (SERIALEE, HCSxxxx) (7.4MB)

Fig.3. IDE Installation – device support options.

installation of Microsoft Windows 10. These instructions should be fine for earlier releases of the Windows operating system, if you have not yet caught up. (You should do though, as earlier versions of Windows have Internet security weaknesses – but that's the subject of a different article!)

Software and hardware tools

The tools are available for use under Linux and Apple Mac OSX, but we will focus on the Windows installation, as this will be the most widely used. Let's start by reviewing what we will be installing.

MPLAB-X

This is actually two programs – MPLAB-X IDE is the source code editor and debugger, really a framework that binds file management, editing, building and debugging in one handy application. When developing projects, this is where you will spend most of your time. MPLAB-X IPE is a stand-alone programmer, a simpler application used to download pre-created programs to a processor. This is useful when programming a batch of devices, or when you are programming a device with a program supplied by someone else.

XC-8

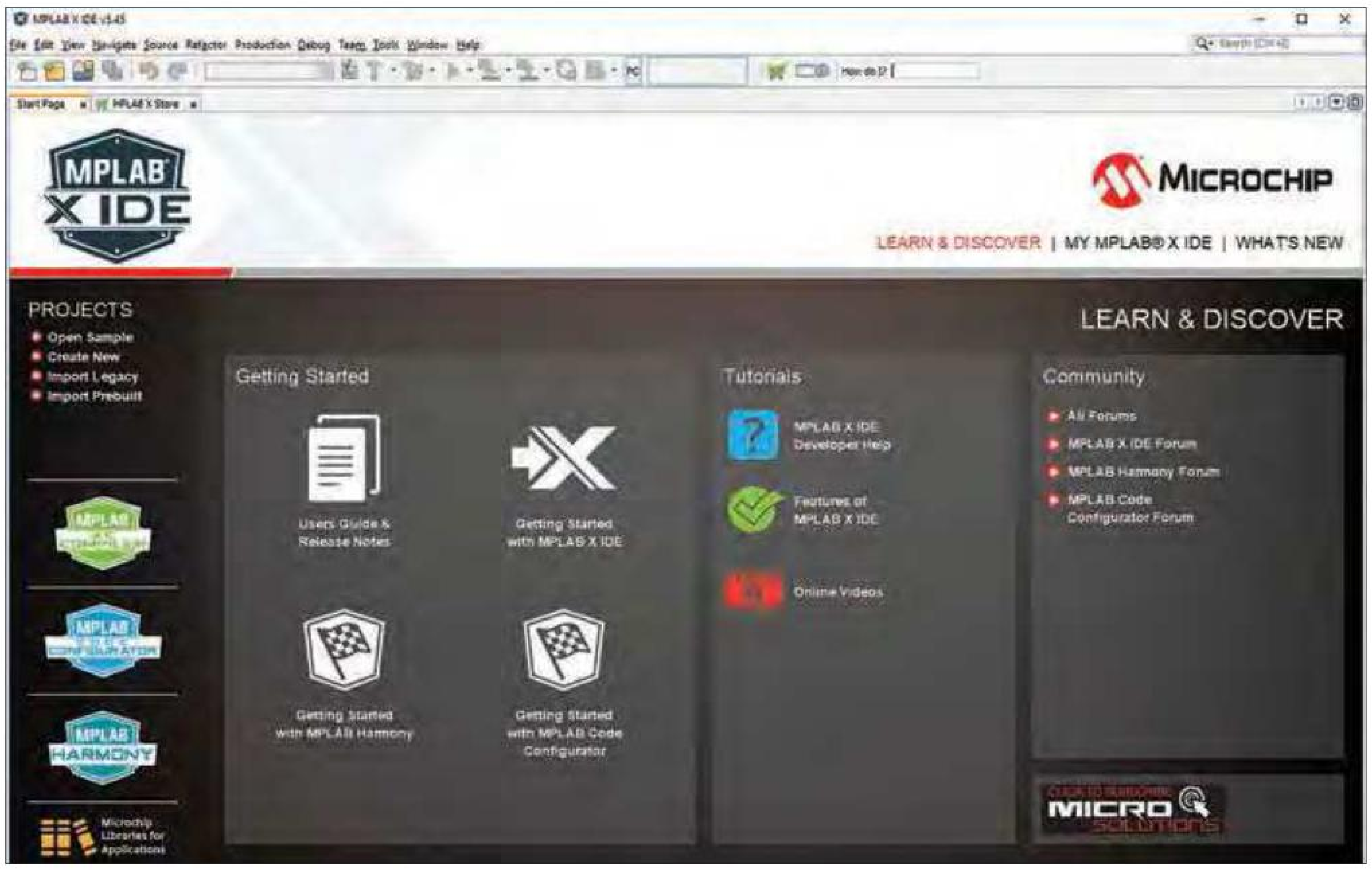
This is the C compiler. It takes the source files for the program you have written and converts them into a format that can be executed directly by the processor (machine code.) XC-8 has to be downloaded and installed independently of MPLAB-X, but once installed, MPLAB-X will find it and use it automatically.

MCC Microchip Code Composer

This is a plug-in to MPLAB-X that provides a simple user-interface, assisted by a graphical selection tool, for automatically generating source code files for configuring the peripherals of the processor to your specific requirements. This does not remove the need to have an understanding of the processor, but it does remove a significant amount of experimentation, and saves a lot of typing. Besides being able to write code for all of the peripherals on the processor, it also contains a number of extremely useful 'higher level' functions that build on top of these peripherals – such as a bootloader, SD-media interface and disk file systems. MCC is installed within MPLAB-X rather than being directly downloaded. It's a tool that takes some getting used to but is very much worth the effort of acquiring familiarity – we will make extensive use of it.

PICkit 4

This final item is hardware rather than software. To program or debug a PIC microcontroller, we need a special interface, which connects to the PC with a supplied USB cable. At around £56 it is not cheap, but it is future proof and will support all your PIC programming needs. The older PICkit 3 also supports the PIC18F47K42 processor and can be found more cheaply, but we recommend the PICkit 4. The instructions for use are identical between the two interfaces. There is also the low-cost MPLAB Snap, a simple PCB that supports PICs, but this has not been tested with our PIC of choice.


MPLAB X IDE v5.45
File Edit View Navigate Source Refactor Production Debug Team Tools Window Help
Start Page
MPLAB X Store
MPLAB X IDE
MICROCHIP
LEARN & DISCOVER | MY MPLAB® X IDE | WHAT'S NEW
PROJECTS
Open Sample
Create New
Import Legacy
Import Prebuilt
LEARN & DISCOVER
Getting Started
Users Guide & Release Notes
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Getting Started with MPLAB Harmony
Getting Started with MPLAB Code Configurator
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MPLAB HARMONY
Microchip Libraries for Applications
MICRO SOLUTIONS

Fig.4. MPLAB X start-up screen.

Microchip do have two other software tools, but we can ignore these. MLA (Microchip Library for Applications) is a now obsolete software package, and Harmony, a software library for PIC32 processors only.

Installation

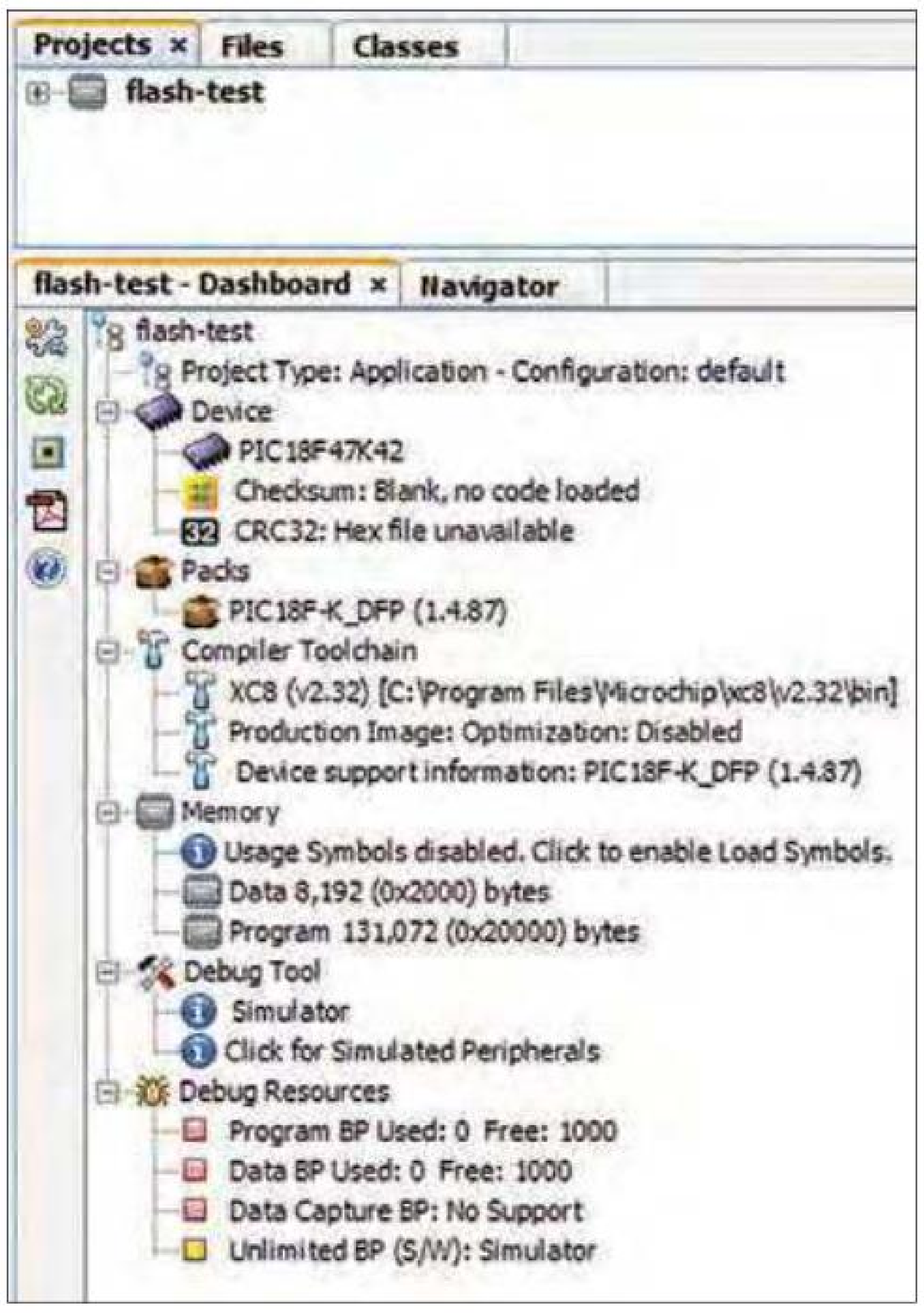
So, let's get started. We will first download MPLAB-X IDE from Microchip's website. Navigate to **http://bit.ly/pe-may21-mcide** and scroll down to the downloads section at the bottom of the page and click in the 'download' label to the right of the **MPLABX-vx.yz-windows-installer.exe** line. At the time of writing, the version number is 5.45. If the current version is later than that, you can find the v5.45 installer under the 'Archives are located here.' link. The file is 1.1GB in size, so make sure you have space on your drive, and a fast Internet connection.

Once downloaded, double-click on the file to start installation. Click 'Accept' and 'Next' when prompted to accept all defaults until you reach the 'Select Applications' window, as shown in Fig.3. We would recommend un-selecting 16-bit, 32-bit and 'Other MCU' support, to save disk space – but go ahead and leave them selected if you anticipate working with other devices later on. Clicking 'Next', then 'Next' again will start the installation process.

Continue installation by accepting 'Install' where prompted, finalised by 'finish', which will result in a number of web pages opening in your browser. You can close these.

Navigate to: **http://bit.ly/pe-may21-mcxc** and scroll down halfway to the 'Downloads' section. Click on the 'MPLAB XC8 Complier v2.32' (or whatever is the latest version) link to start the download. It does not matter if this is a more recent version. Click on the file to start the program and accept all default options to perform the installation. When prompted to complete the licensing information, just click next, to select the free option, followed by 'Finish'.

You can now double click on the 'MPLAB X IDE' icon on your desktop to start the application. On first start-up you may see a warning from your security software that MPLAB is trying to access the Internet – click OK to this; MPLAB 'dials home' to check for updates, and this is a good thing, from a reputable organisation like Microchip. Now, you



Projects
Files
Classes
flash-test
flash-test - Dashboard
Navigator

flash-test
Project Type: Application - Configuration: default
Device
PIC18F47K42
Checksum: Blank, no code loaded
CRC32: Hex file unavailable
Packs
PIC18F-K_DFP (1.4.87)
Compiler Toolchain
XC8 (v2.32) [C:\Program Files\Microchip\xc8\v2.32\bin]
Production Image: Optimization: Disabled
Device support information: PIC18F-K_DFP (1.4.87)
Memory
Usage Symbols disabled. Click to enable Load Symbols.
Data 8,192 (0x2000) bytes
Program 131,072 (0x20000) bytes
Debug Tool
Simulator
Click for Simulated Peripherals
Debug Resources
Program BP Used: 0 Free: 1000
Data BP Used: 0 Free: 1000
Data Capture BP: No Support
Unlimited BP (S/W): Simulator

Fig.5. Initial project setup.

are greeted with the start-up screen, as shown in Fig.4.

At this point we are ready to start developing programs. We are however missing one final tool, MCC, which will make our lives a lot simpler. We can install this through MPLAB-x IDE, so let's go ahead and do that now.

On the main menu bar, click on 'Tools', followed by 'Plugins'. Click on 'Available Plugins', then scroll down if needed and click to enable 'MPLAB Code Configurator'. Now click 'Install'. Click 'Next', 'Agree' Followed by 'Install'.

Click 'Finish' to complete the installation, which requires a restart of the PC.

Using MPLAB-X IDE

Following a reboot, MPLAB-X IDE will restart, giving you a start-up screen similar to Fig.4.

We assume many of you will be familiar with MPLAB-X (but don't worry if that's not the case, we will be bringing everyone on this journey,) but expect that the MCC tool will be new. Let's take a quick look at what it provides by building a simple test program.

First, we plug the PICkit 4 device to the PC, so it will be detected by MPLAB-X.

From the main menu of MLPAB-X we click 'File' followed by 'New Project...'. In the dialogue that pops up, click on 'Standalone Project', followed by 'Next'. Whenever you are creating a new project, this is always the appropriate option to choose. In the 'Device:' field of the following dialogue box, scroll down or type in PIC18F47K42. Then under the 'Tool' drop-down, select PICkit 4. You have the option to pick the simulator, which if you are following along at home without hardware would be a good choice. Then, click 'Next'.

In the next dialogue we get to choose which compiler we want MPLAB-X to use. The XC8 compiler we just downloaded should appear in the list, so click on that and then 'Next'. If you wanted to write your application in assembly language, you could have selected that instead. However, we will be focusing on using the 'C' programming language in our examples.

We now get to give our project a name and specify where the files will be place. Type in **gpios** for the project name, leave the other options as they are and click 'Finish'.

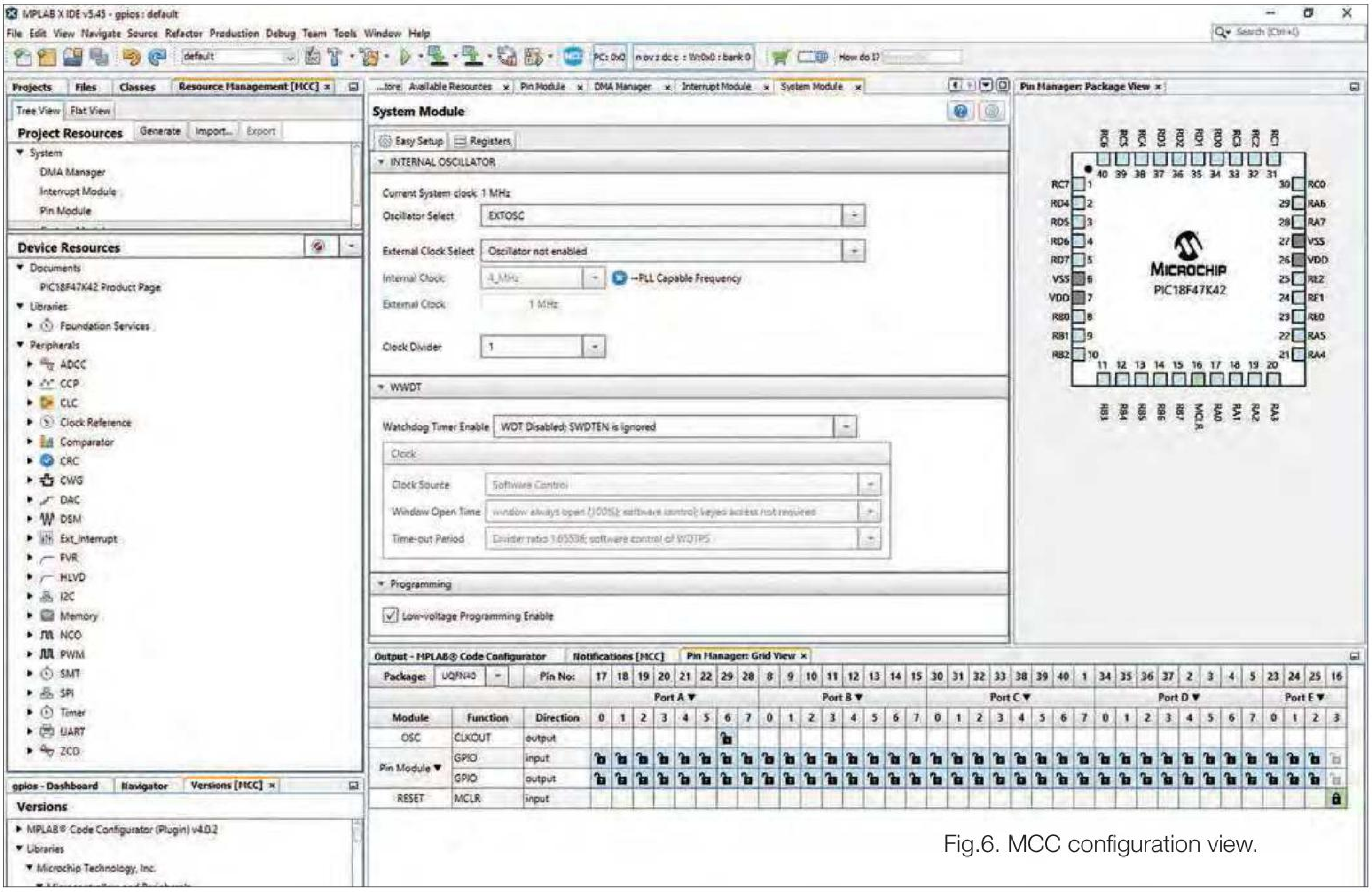
At this stage we have created the project, as can be seen in the left-hand dialogues, as shown in Fig.5. The top window shows the files, and the lower the project configuration. At this point, no source files exist.

From here, we would normally create a **main.c** file and start writing software, but let's see how MCC helps us. First though, here are the requirements for our simple project. Turn on the green LED, which is connected to digital pin RE2. Set an alternating high-low pattern on the pins of HDR16 (the LCD interface header.)

With that in mind, click on the blue MCC icon in the top menu bar.

On first launch you will be prompted to store the MCC configuration file – just click save, the default name and location are acceptable. Then, MPLAB-X reconfigures itself to show MCC's graphical user interface, as shown in Fig.6. Notice the long list of entries under 'Device Resources' – the MCC tool understands all of the peripherals on our microcontroller, and can generate code for them.

This is a large departure from classical source code editors, but it highlights the



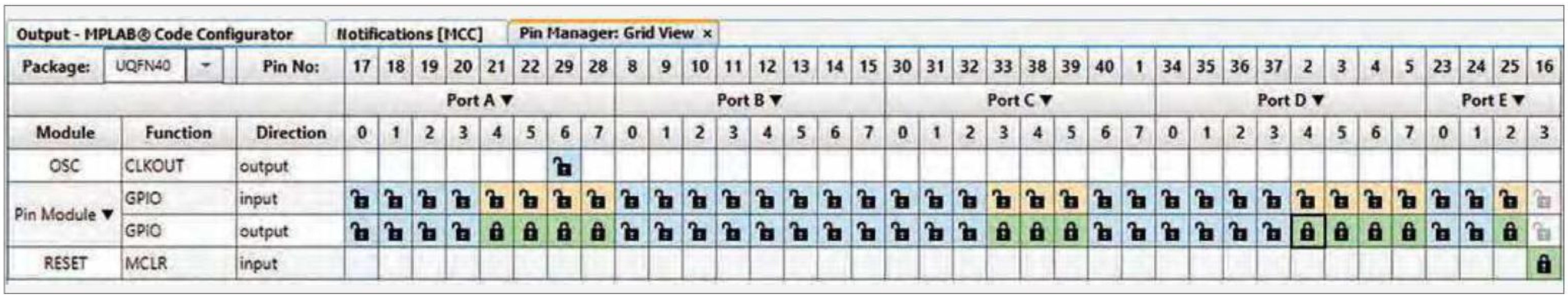
MPLAB X IDE v5.45 - gpios : default
File Edit View Navigate Source Refactor Production Debug Team Tools Window Help
PC: 0x0
n ov z dc c : W:0x0 : bank 0
How do I?
Projects
Files
Classes
Resource Management [MCC]
Tree View
Flat View
Project Resources
Generate
Import...
Export
System
DMA Manager
Interrupt Module
Pin Module
Device Resources
Documents
PIC18F47K42 Product Page
Libraries
Foundation Services
Peripherals
ADCC
CCP
CLC
Clock Reference
Comparator
CRC
CWG
DAC
DSM
Ext_Interrupt
FVR
HLVD
I2C
Memory
NCO
PWM
SMT
SPI
Timer
UART
ZCD
gpios - Dashboard
Navigator
Versions [MCC]
Versions
MPLAB® Code Configurator (Plugin) v4.0.2
Libraries
Microchip Technology, Inc.
...tore
Available Resources
Pin Module
DMA Manager
Interrupt Module
System Module
System Module
Easy Setup
Registers
INTERNAL OSCILLATOR
PLL Capable Frequency
WWDT
Clock
Programming
Output - MPLAB® Code Configurator
Notifications [MCC]
Pin Manager: Grid View
Pin Manager: Package View
MICROCHIP
PIC18F47K42

Current System clock: 1 MHz
Oscillator Select: EXTOSC
External Clock Select: Oscillator not enabled
Internal Clock: 4_MHz
External Clock: 1 MHz
Clock Divider: 1
Watchdog Timer Enable: WDT Disabled; SWDTEN is ignored
Clock Source: Software Control
Window Open Time: window always open (100%); software control; keyed access not required
Time-out Period: Divider ratio 1:65536; software control of WDTPS
☑ Low-voltage Programming Enable

Package: UQFN40

Module	Function	Direction
OSC	CLKOUT	output
Pin Module	GPIO	input
	GPIO	output
RESET	MCLR	input

Fig.6. MCC configuration view.



Package:	UQFN40 ▾	Pin No:	17	18	19	20	21	22	29	28	8	9	10	11	12	13	14	15	30	31	32	33	38	39	40	1	34	35	36	37	2	3	4	5	23	24	25	16
			Port A ▼								Port B ▼								Port C ▼								Port D ▼								Port E ▼			
Module	Function	Direction	0	1	2	3	4	5	6	7	0	1	2	3	4	5	6	7	0	1	2	3	4	5	6	7	0	1	2	3	4	5	6	7	0	1	2	3
OSC	CLKOUT	output							🔓																													
Pin Module ▼	GPIO	input	🔓	🔓	🔓	🔓	🔓	🔓	🔓	🔓	🔓	🔓	🔓	🔓	🔓	🔓	🔓	🔓	🔓	🔓	🔓	🔓	🔓	🔓	🔓	🔓	🔓	🔓	🔓	🔓	🔓	🔓	🔓	🔓	🔓	🔓	🔓	🔓
	GPIO	output	🔓	🔓	🔓	🔓	🔒	🔒	🔒	🔒	🔓	🔓	🔓	🔓	🔓	🔓	🔓	🔓	🔓	🔓	🔓	🔒	🔒	🔒	🔓	🔓	🔓	🔓	🔓	🔓	🔒	🔒	🔒	🔒	🔓	🔓	🔒	🔓
RESET	MCLR	input																																				🔒

Fig.7. Output pins defined.

value of an IDE – although we are about to click on graphical images and click on icons, the results end up as text-based source files that we can edit and add our own additional requirements later on. We can switch between the two code editing methods too. For now, however, we will continue in the MCC tool and implement our (somewhat contrived) program requirements without typing a single line of code.

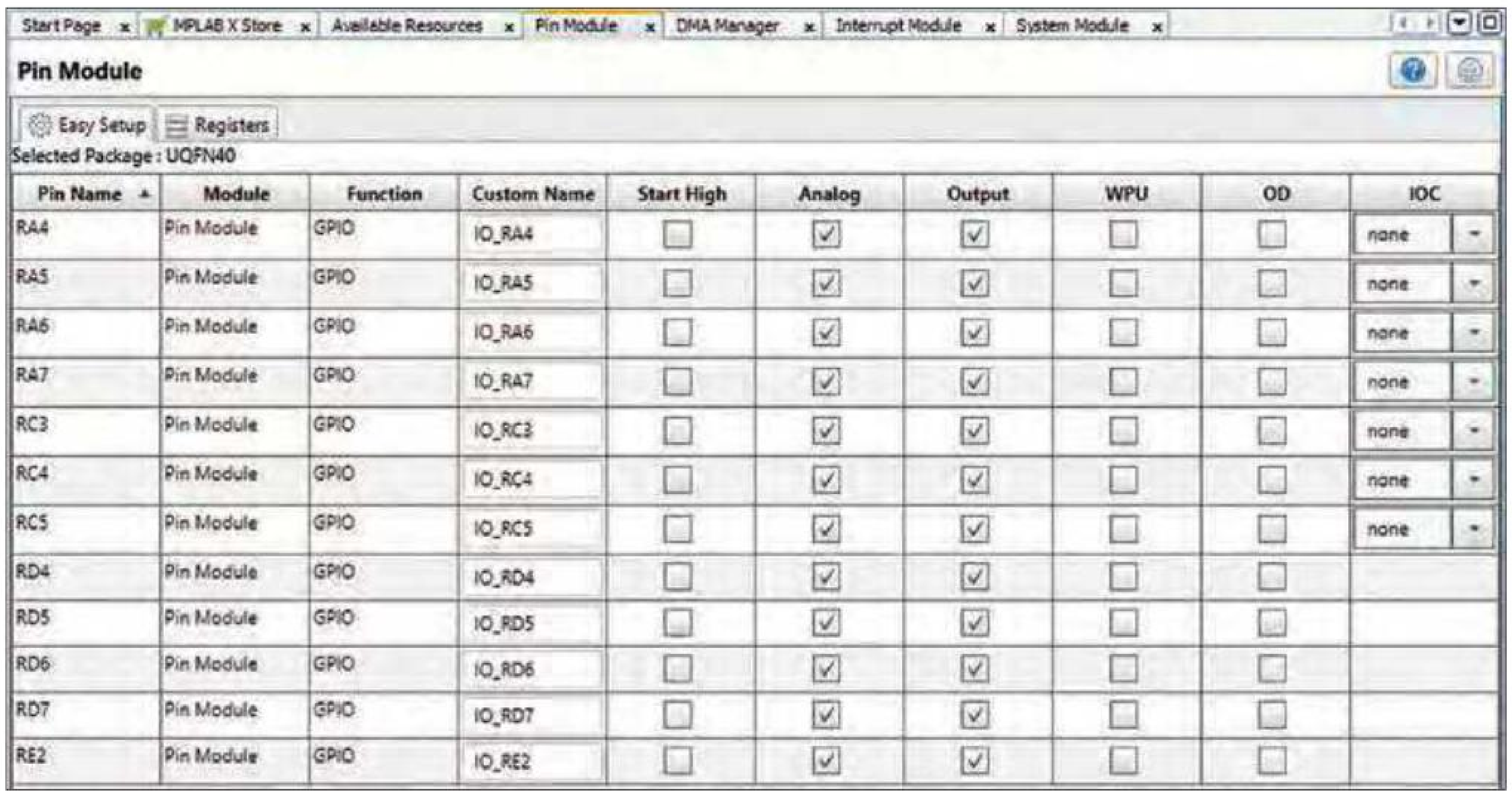
The details that follow work with and without hardware (using the simulator in that case) so feel free to follow along at home.

Conveniently, on start-up the GUI displays the key dialogue – The 'System Module' page, where we get to define the chip's start-up behaviour. These selections get programmed into the processor's configuration bits and define how the processor configures itself before your software starts running.

Click on the 'Oscillator Select' field and select HFINTOSC, the high frequency internal oscillator – we have chosen to not use an external high frequency crystal oscillator. Then under 'HF Internal Clock' we chose '16_MHz', as this is not exactly a high-speed program.

Pins and things

From here we can move down to the 'Pin Manager: Grid View' in the lower dialogue. Here we can single click each of the GPIO pins, in the 'output' row, to assign our desired pins to be configured as outputs. As you click, the icon changes from unlocked to locked. You can see the result in Fig.7.

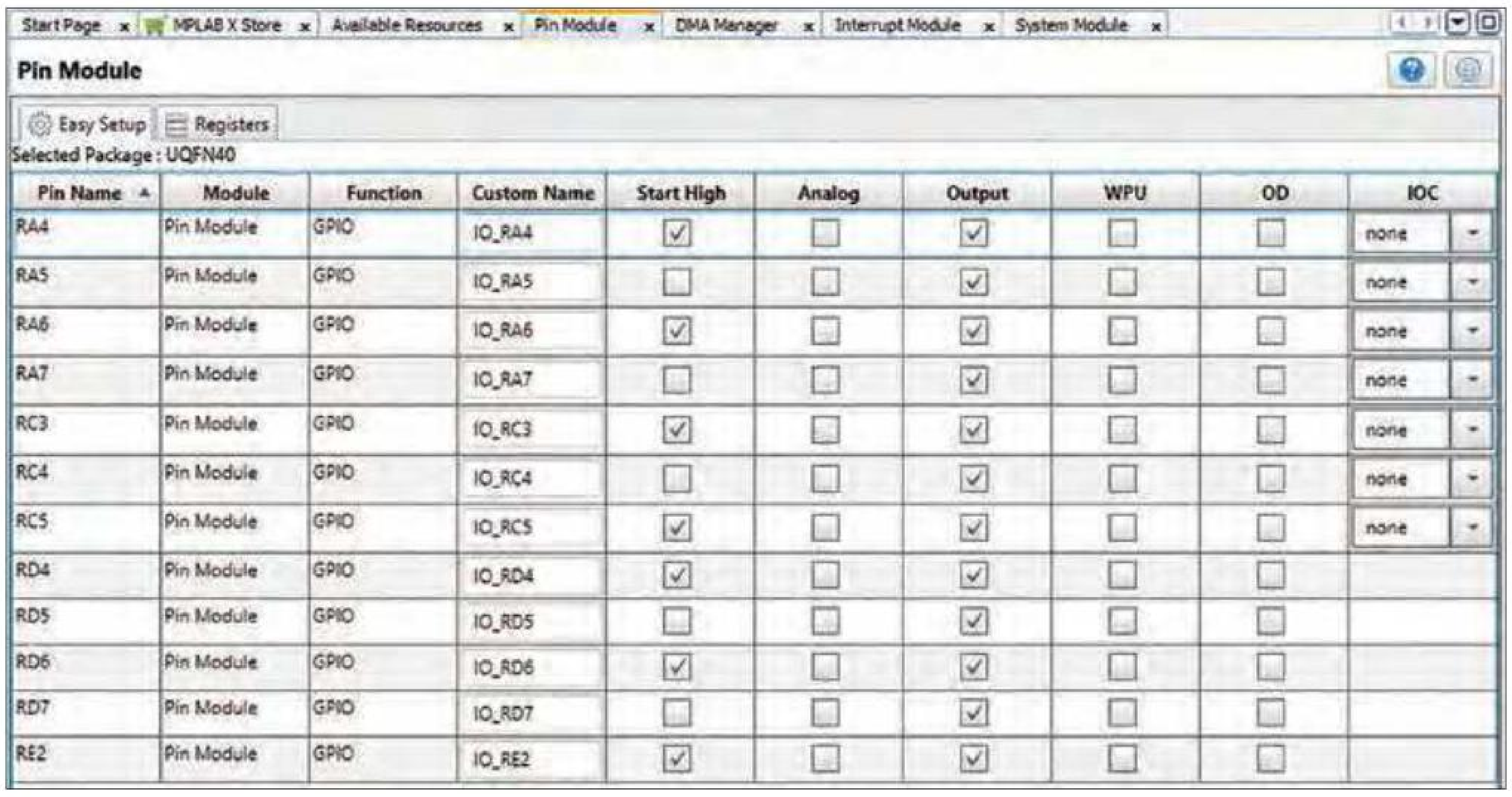


Pin Module

Selected Package : UQFN40

Pin Name ▲	Module	Function	Custom Name	Start High	Analog	Output	WPU	OD	IOC
RA4	Pin Module	GPIO	IO_RA4	☐	☑	☑	☐	☐	none ▾
RA5	Pin Module	GPIO	IO_RA5	☐	☑	☑	☐	☐	none ▾
RA6	Pin Module	GPIO	IO_RA6	☐	☑	☑	☐	☐	none ▾
RA7	Pin Module	GPIO	IO_RA7	☐	☑	☑	☐	☐	none ▾
RC3	Pin Module	GPIO	IO_RC3	☐	☑	☑	☐	☐	none ▾
RC4	Pin Module	GPIO	IO_RC4	☐	☑	☑	☐	☐	none ▾
RC5	Pin Module	GPIO	IO_RC5	☐	☑	☑	☐	☐	none ▾
RD4	Pin Module	GPIO	IO_RD4	☐	☑	☑	☐	☐	
RD5	Pin Module	GPIO	IO_RD5	☐	☑	☑	☐	☐	
RD6	Pin Module	GPIO	IO_RD6	☐	☑	☑	☐	☐	
RD7	Pin Module	GPIO	IO_RD7	☐	☑	☑	☐	☐	
RE2	Pin Module	GPIO	IO_RE2	☐	☑	☑	☐	☐	

Fig.8. GPIO pin configurations.



Pin Module

Selected Package : UQFN40

Pin Name ▲	Module	Function	Custom Name	Start High	Analog	Output	WPU	OD	IOC
RA4	Pin Module	GPIO	IO_RA4	☑	☐	☑	☐	☐	none ▾
RA5	Pin Module	GPIO	IO_RA5	☐	☐	☑	☐	☐	none ▾
RA6	Pin Module	GPIO	IO_RA6	☑	☐	☑	☐	☐	none ▾
RA7	Pin Module	GPIO	IO_RA7	☐	☐	☑	☐	☐	none ▾
RC3	Pin Module	GPIO	IO_RC3	☑	☐	☑	☐	☐	none ▾
RC4	Pin Module	GPIO	IO_RC4	☐	☐	☑	☐	☐	none ▾
RC5	Pin Module	GPIO	IO_RC5	☑	☐	☑	☐	☐	none ▾
RD4	Pin Module	GPIO	IO_RD4	☑	☐	☑	☐	☐	
RD5	Pin Module	GPIO	IO_RD5	☐	☐	☑	☐	☐	
RD6	Pin Module	GPIO	IO_RD6	☑	☐	☑	☐	☐	
RD7	Pin Module	GPIO	IO_RD7	☐	☐	☑	☐	☐	
RE2	Pin Module	GPIO	IO_RE2	☑	☐	☑	☐	☐	

Fig.9. GPIO pins, configured.

Having defined the pins we need as being outputs, click on the 'Pin Manager' tab at the top of the MPLAB-X window. The pins you have selected as used by your application appear here, with their configuration settings, as shown in Fig.8.

This is where things get interesting. Configuring PIC processor GPIO pins has always been a pain, especially with some being analogue by default, requiring additional code to reverse that. Here, you have a clear table. Let's go ahead and modify this table. We have already defined the pin settings to be output, so all we need to do is set the pins we want to high level as ticks in the 'Start High' column, and turn off 'Analog' in all cases. The final result is shown in Fig.9. Although this looks a bit odd, it should result in the green LED being turned on, and an alternating high/low pattern on HDR 16.

To convert this set of graphical settings into code, we have to click on the 'Generate' button on the tab list of the 'Project Resources' dialogue on the left. Once finished, the generator has created our main source file and the 'driver' files required to implement our requirements. We don't need to edit code at this stage; we just click the run icon on the main menu list.

With the PICkit 4 plugged in and power applied, the LED lit and the header pins had the expected voltages. With that running we have confirmed our development environment installation is complete, and we are now ready to start our first real project!

Coming up

With the development board supporting an LCD, SD-Media Card, PC interface, servo drivers and a Wi-Fi interface the range of projects that could be supported by this board is enormous. If you have an interesting idea that you would like to see tackled in an article, drop us an email (**pe@electronpublishing.com**) via the editor – you could see your idea in print!

In our next article, we will fire up the LCD and SD-Media interfaces and test out data exchange between the development

AUDIO OUT

By Jake Rothman

Microphone Preamplifier (for Vocoder) – Part 1

I'm going to start an ongoing series of top-quality modules for studio work. Soon I'll be doing an analogue vocoder, to make that sound personified for eternity by ELO's *Mr Blue Sky* and Queen's *Radio Ga Ga*. The first thing we need for this project is a microphone pre-amplifier, which is the topic of this month and next. I need to buy time to get the Vocoder PCBs together, since the original design used the obsolete CA3080 chip. Production was discontinued in 2005 to the dismay of the music technology industry. The basic mask of this chip lives on in the LM13700, which fortunately is still being made. To hear the Vocoder in use, visit my son's Soundcloud and listen to: **http://bit.ly/pe-may21-voco**

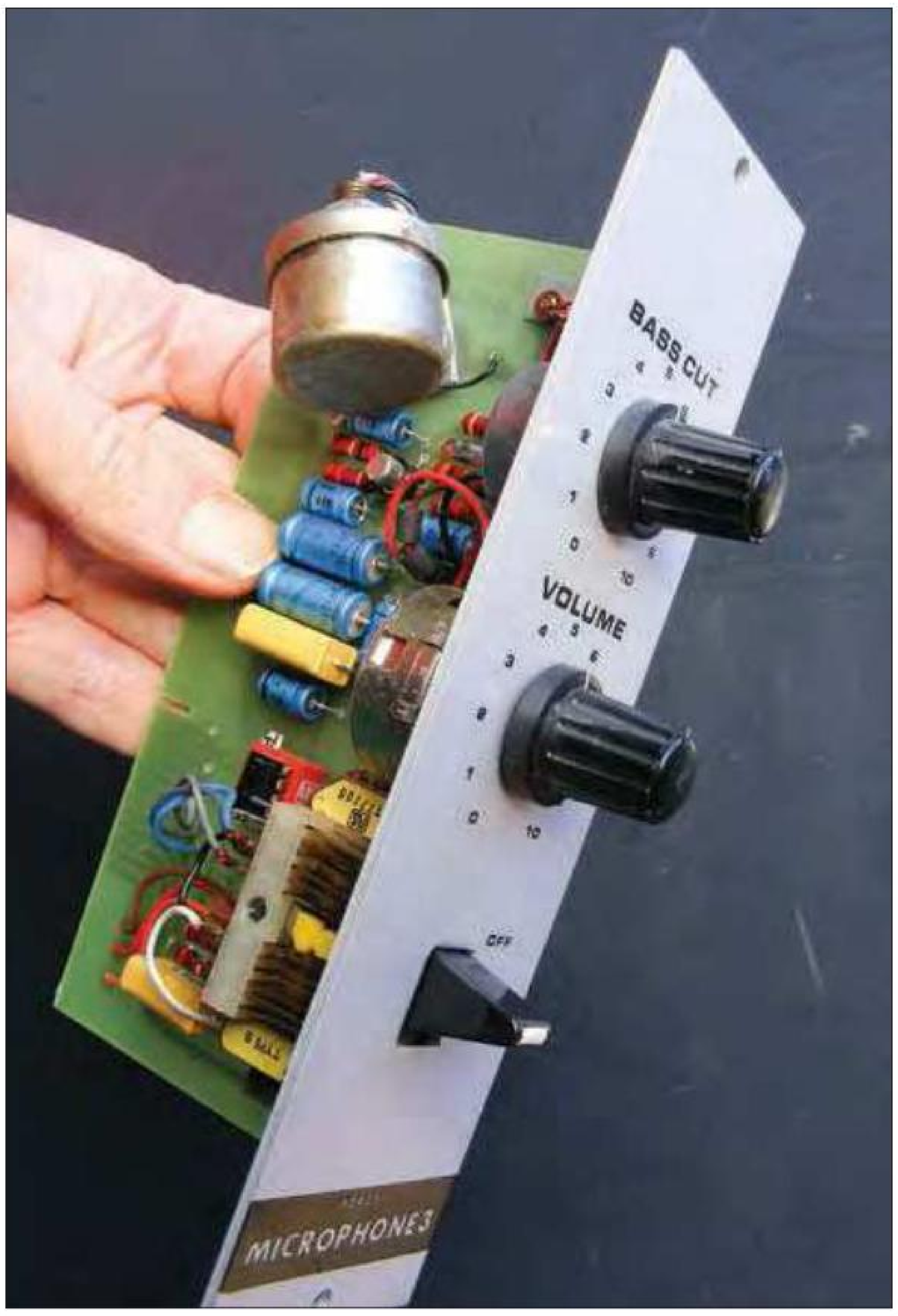


Fig.1. Early microphone preamplifiers used a step-up transformer on the input – here, the Mu-metal can at top. This 1970s Astronic module used a BC109 input transistor followed by a 741 op amp. The transformer, an OEP X187B, costs £64.00 inc VAT from RS (stock No. 210-6352). The swivel mounting to find the minimum hum pick up was a great idea.

Standing alone

A vocoder could use just a single inverting op amp stage for a mic preamplifier, like the Korg and Roland designs. However, I've found using top quality external pre-amps and equaliser units with vocoders gave better results. My design can be made into a fully fledged stand-alone unit comparable with those costing hundreds of pounds.

Input impedance and noise

Microphones require dedicated amplifiers because their output is often only a few mV at an output impedance of around 25Ω to 600Ω. This means standard amplifier circuits suffer from additional noise because they have an optimum source impedance (OSI) for minimum noise, which is generally much higher than the microphone's output impedance. For the 5534 op amp the OSI is about 5kΩ, which means that special tricks have to be used to reduce the effective OSI. Full-noise analysis of amplifying devices is complex, there's also flicker noise, shot noise, popcorn noise, contact noise, contamination effects, thermal leakage currents and crystal defects. We haven't got the space to cover them all here, but do see: **http://bit.ly/pe-may21-noise**

The oldest method to match a low impedance to a higher one is a step-up transformer from the microphone to the amplifier, shown in Fig.1. This is still regarded by many studio engineers as the best sounding approach. Naturally there are problems associated with transformers: they have a droopy frequency response at the extremes, hum pickup, low-frequency distortion and cost around £60.00.

The most cost-effective method (ie, not using a transformer) of reducing the effective OSI is to use a pair of low-base-spreading resistance (R_{bb}) bipolar transistors run at a relatively high collector current, followed by op amps. Low resistance is required because all resistances make Johnson noise, a result of thermal agitation of electrons. The higher the resistance the worse the noise. (This can be reduced by cooling your electronics with liquid helium!) But unless you are into astronomical electronics with its astronomical costs, we'll leave esoteric cryogenics to Jodrell Bank. It's best just to follow the basic audio rules for low-noise design, 'keep all your resistors and impedances as low as possible' and 'do as much amplification in the first stage as possible'. This is so any noise produced isn't amplified later.

ElectroVoice RE20

Fig.2. The Electro Voice RE20 is a microphone that benefits from a low-noise low impedance mic preamplifier. It's the 'sound of American FM radio'. (Photo: Harvey Rothman)

A microphone (or any source) adds its own noise. Microphones have Johnson noise and that produced by Brownian motion of air molecules on the diaphragm. The aim is to make the amplifier noise at least equal to the inherent noise of the source. Then the noise will only increase by 3dB.

All condenser microphones have an internal amplifier, and this is often the dominant electrical noise source for these types of microphones. Some dynamic (electromagnetic) microphones, such as the American broadcaster's mic of choice, the Electro Voice RE20 with 150Ω output impedance shown in Fig.2, need an especially good preamplifier. My design has an optimum source impedance of around 200Ω, but the actual input impedance is around 10kΩ to reduce loading. This preamplifier even managed to make my very cheap (£5) Sony F-99A stereo dynamic mic sound good, before it always sounded muffled and noisy – see Fig.3. I had to snip off the F-99A's mono jack plug cable and rewire it for balanced operation with XLR connectors.

Components

For consistency, mic preamplifier input transistors have to be selected for low noise. Most audio companies use specially made test jigs to screen the transistors and op amps. When I worked in the mixer industry in the 1980s the noisy ones were weeded out and used in bass equalisation and LED drivers. The really bad ones were put into synth noise generators. There was a whole selection of noise grades. It is possible to buy pre-selected, low-noise devices, but you pay for it. More modern devices are much more consistent.

Transistors

Low R_{bb} transistors are hard to find because it's a parameter hardly ever specified in data sheets and difficult to measure. It was only provided for such devices as the obsoleted Rohm and Toshiba transistors, made especially for moving-coil vinyl pick-up preamplifiers, such as the 2SB737 with an R_{bb} of 2Ω. There is now a thriving industry selling fakes from Hong Kong on eBay, and yes, I have a drawer full of these useless transistors.

Many engineers have their favourite low-noise transistors selected from general devices. For years, one popular one was the 2N4403 which had an R_{bb} of 40Ω. Europe's first low-noise transistor, the BC109 comes in at 400Ω.

Horowitz and Hill, *The Art of Electronics* authors measured loads of devices and their choice for a ribbon mic preamp (the lowest impedance device in audio) was the Ferranti/Zetex/Little Diode ZTX751, which was 1.7Ω.

The other method is to put lots of small transistors in parallel, a trick used in Ortofon preamplifiers. Other popular types have been the BD139/40 power transistors at 30Ω, and the TO5 types such as the BC461 and BC143 at 20Ω. I use the Philips BFW16A, a medium power-RF transistor, which because of its interdigitated structure, is effectively many small transistors in parallel, reducing resistance. A photo of the chip is shown in Fig.4 and the R_{bb} comes in at around 5Ω. Finding a surplus stash of 200 was also a factor in deciding their use.

PNP devices are sometimes slightly quieter (also lower R_{bb}) than complementary NPN types. John Linsley-Hood said this was due to lower noise generated at the surface of the crystal resulting from the recombination of holes and electrons. I'm not going to go into the physics behind this, but I've found the difference to be rather subtle in practice. I'll put provision on the PCB for reversing polarity by links to different power rails if required. The lowest noise transistors are JFETs which don't have partition noise (where the base current splits off from the collector current). The classic device is the 2SK170, a real low-noise FET, no longer made of course. There are replacements from InterFET which cost a fortune.

Generally, the larger the current the devices are run at the lower the OSI and noise up to an optimum point, specific to the device. This is often indicated on a special noise factor diagram shown in Fig.5. Noise factor is the difference in dB between the theoretical Johnson noise and the actual noise.

Op amps

My go-to audio op amp is the 5532/4. Strangely, you effectively get two 5534 op amps in the 5532 dual op amp for less than the price of one! Many more 5532 duals are made than singles, which is reflected in the lower cost. There are small differences; the single has an external compensation capacitor which gives better high frequency response at high gains. Also, the 5534 has slightly lower noise, especially the selected 5534A.

Op amp noise is usually specified in nanovolts per root hertz (nV/√Hz) with the 5534A at 3.5nV/√Hz and the 5532 at 5nV/√Hz. Good discrete transistors are typically 0.5 to 1nV/√Hz. To work out the actual voltage produced depends on the noise current (pA) as well as the noise voltage and circuit configuration. The bandwidth is also important. For audio work we usually take that to be 20kHz, so remember to do the square root of 20,000 (~141). Thus, our 5nV/√Hz becomes 5×141=705nV.

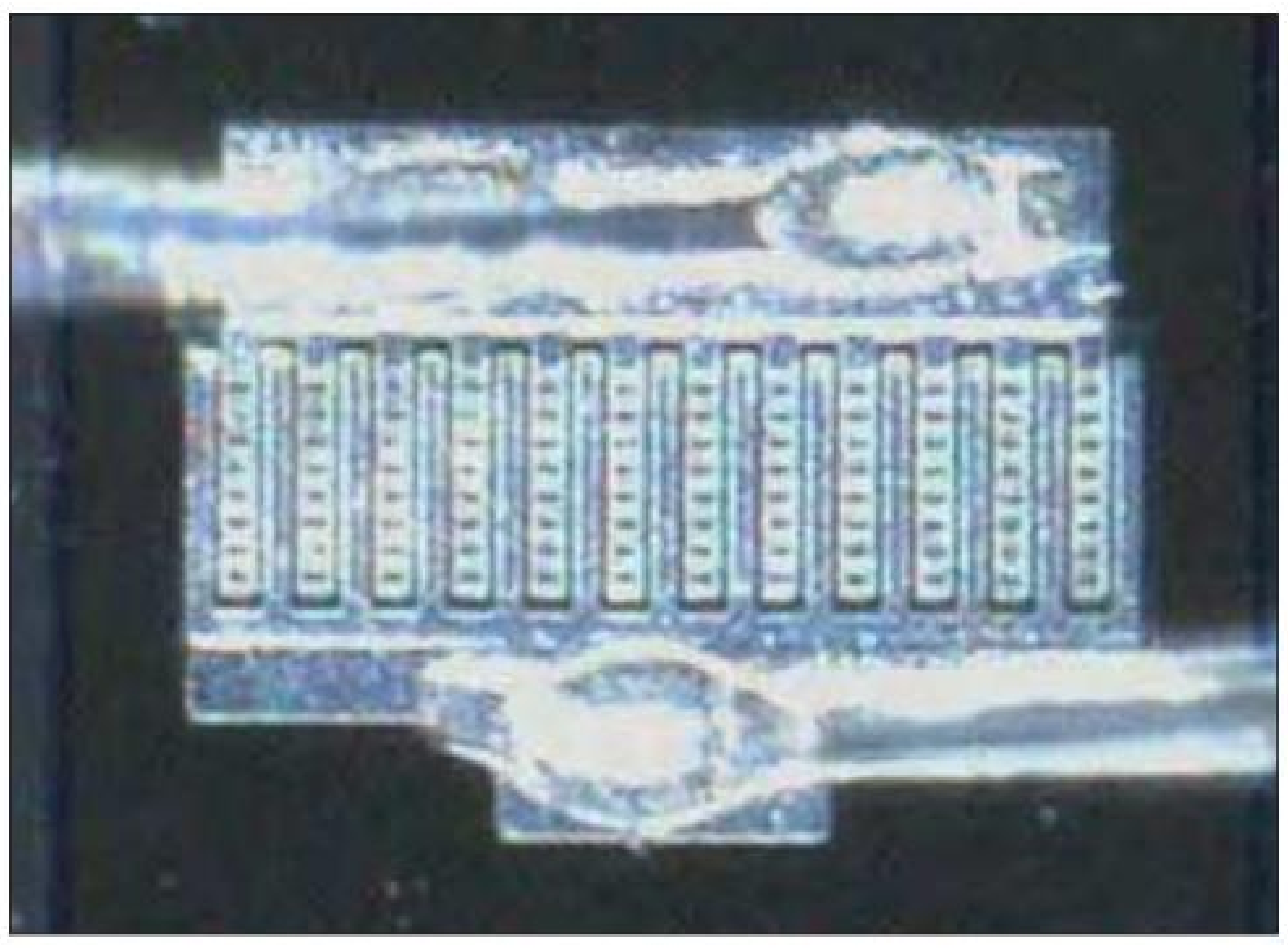


Fig.4. The BFW16A chip. This transistor is composed of interdigitated strips of small transistors. This reduces the base-spreading resistance R_{bb} to around 5Ω. An ideal choice for low-impedance amplifiers. (Photo by Dr Joe Botting)

There are very few op amps that are a useful upgrade from the 5534/2 in audio work. The only one I have found is the LM4562. This is only available in a dual, so for future upgrades we need to design the PCB for dual devices. Note also that the maximum supply for the LM4562 is ±18V, rather than ±22V for the 5532/4.

Resistors

As well as Johnson noise, resistors also generate additional noise caused by micro arcs between the conducting particles. This noise is proportional to the current flowing and is called 'excess noise'. The more homogenous the resistive material, the better. The best are Charcroft Vishay tantalum foil resistors, and the worst are old Erie carbon composition resistors, which are basically soot particles bound together with glue. For cost-effective professional audio work, axial-leaded 0.25W

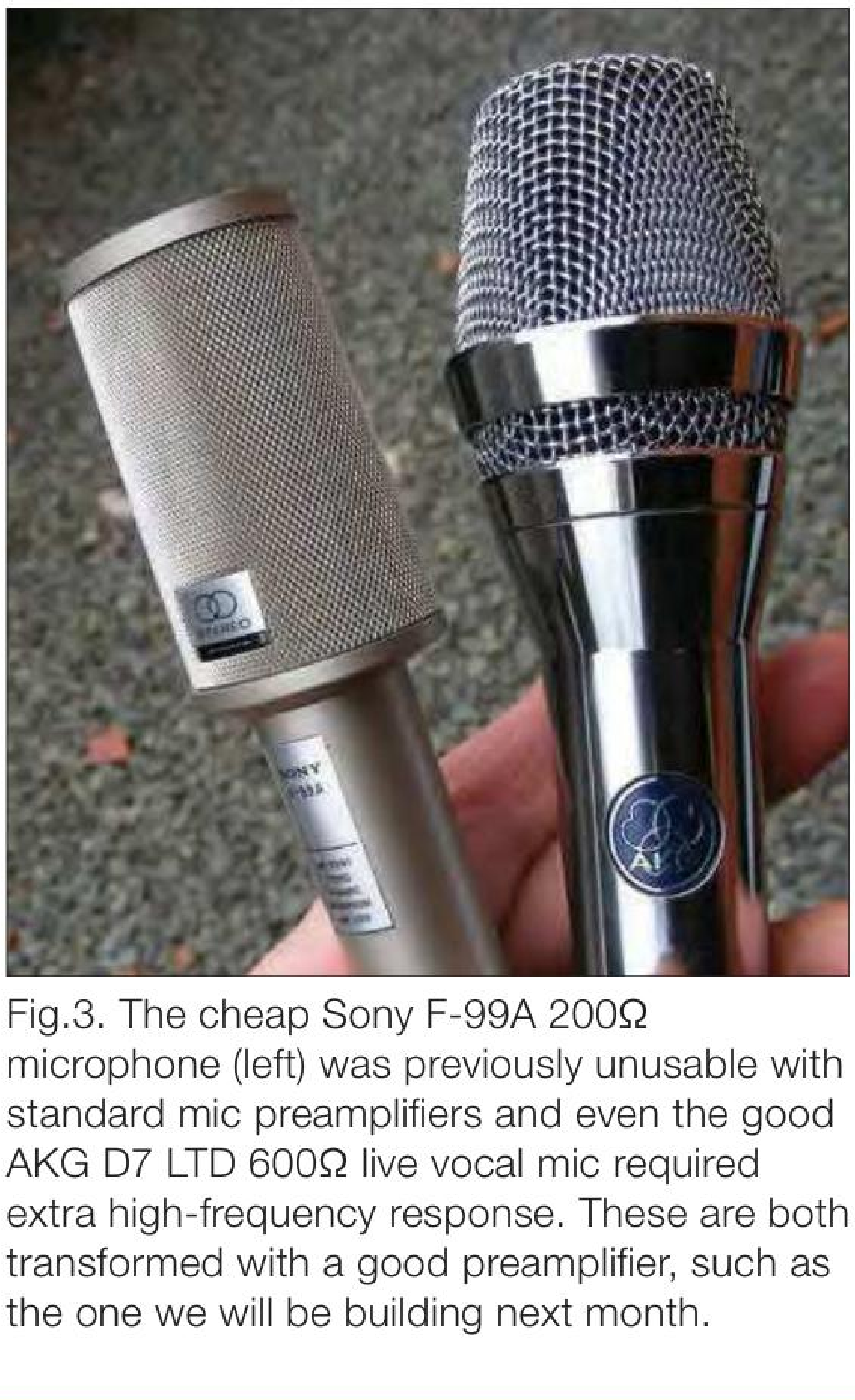


Fig.3. The cheap Sony F-99A 200Ω microphone (left) was previously unusable with standard mic preamplifiers and even the good AKG D7 LTD 600Ω live vocal mic required extra high-frequency response. These are both transformed with a good preamplifier, such as the one we will be building next month.

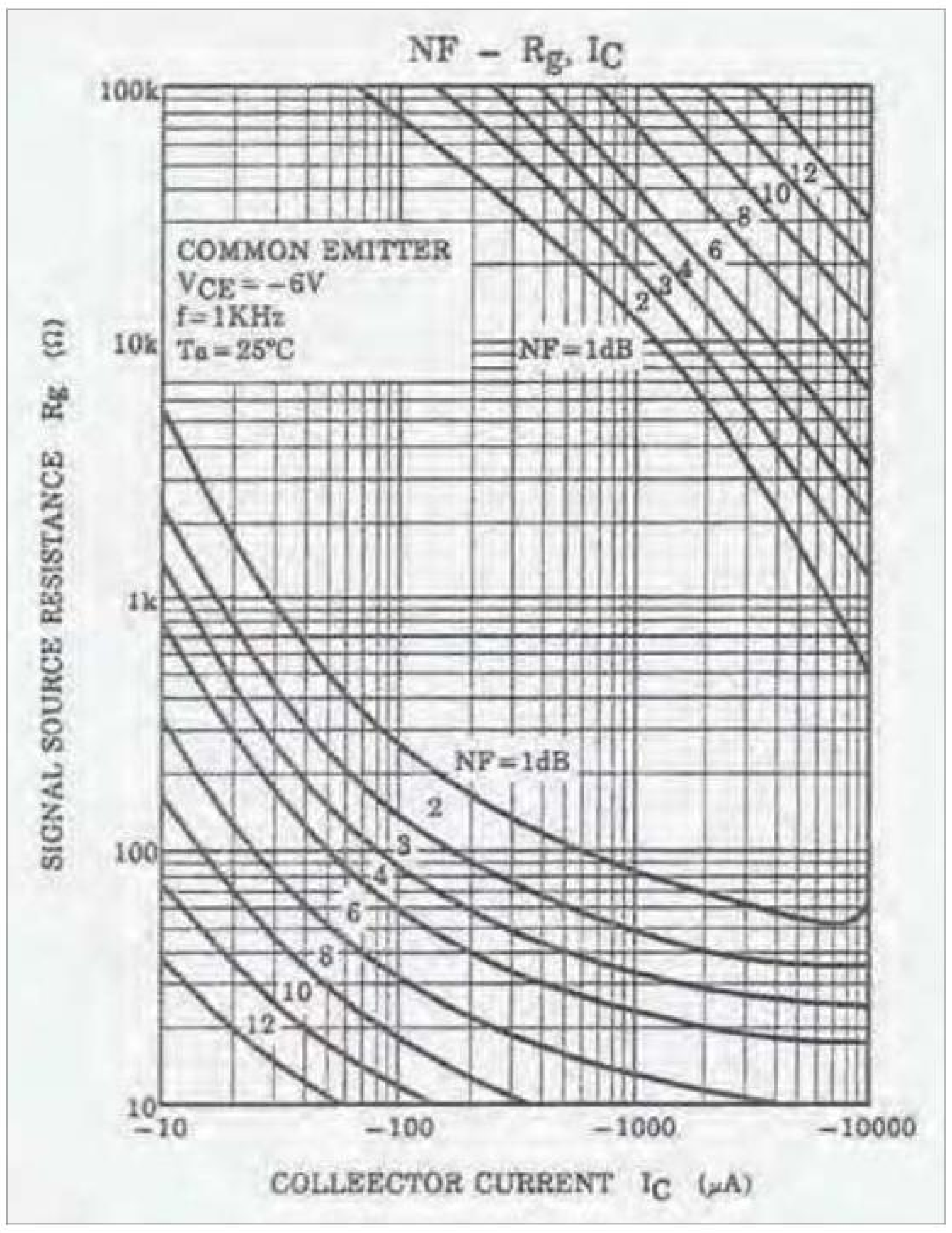


Fig.5. Noise figure map for the Toshiba 2SA1312, a modern SMT PNP low-noise audio transistor. It can be seen that to get the lowest noise factor of 1dB at the lowest source resistance of 40Ω a collector current of 7mA is needed. Note the specification for this noise factor can vary between 0.2db and 3dB, so selection is still required.

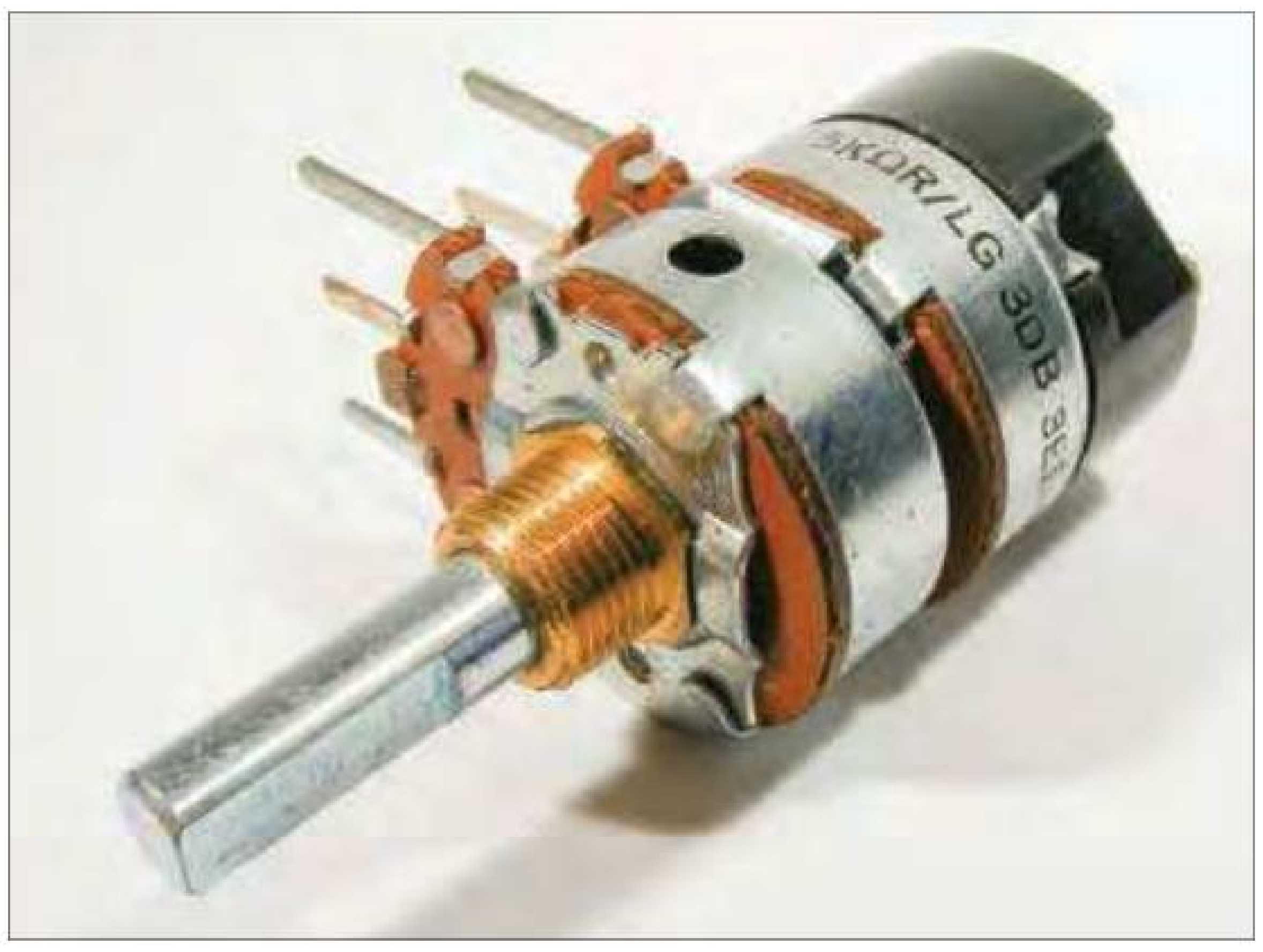


Fig.6. A special Blore Edwards pot for the gain control (VR1). It is a CTS 45 series, 5kΩ reverse-log dual-gang with switch type.

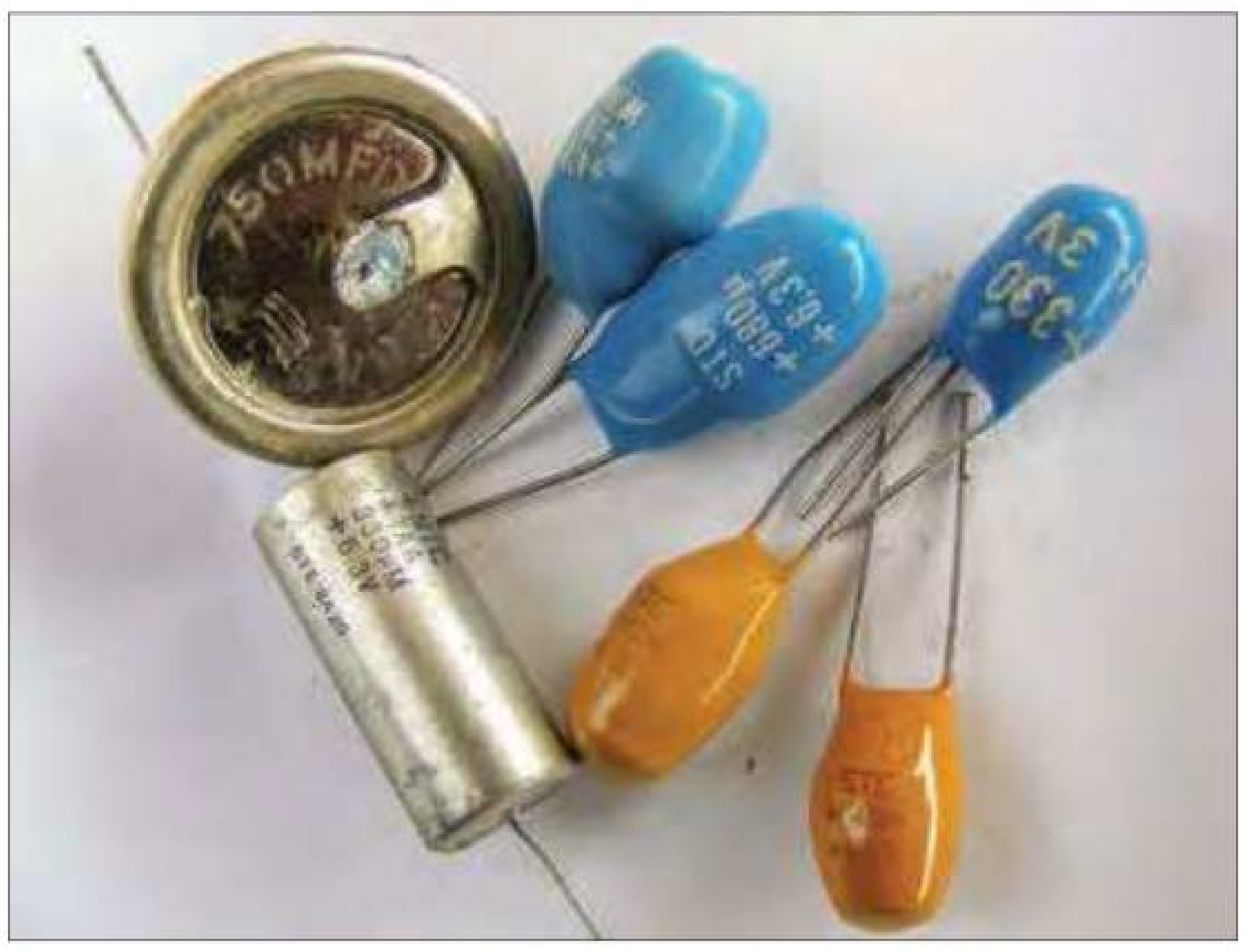


Fig.7. Tantalum capacitors offer high values with low leakage currents (10-20μA) – although manufacturers won't guarantee it. (You should check your devices!) Getting values high enough (over 100μF) can be difficult. The metal capacitor to the right is a bolt-mounted Castanet wet type and the axial capacitor is a standard metal-case solid European TAA equivalent to US CTS13.

full-size MR25 vapour-deposited Nichrome metal-film resistors are generally used. Watch out for the cheap metal-film SMT types that are really thick-film cermet types, which are noisier. Increasing the volume of resistive material increases the effective number of particles, so higher wattage types are generally quieter.

Going to pot

The gain control pot is a difficult component to obtain because it has to be anti-log (C taper), in that the rate of change of resistance gets less as the pot is rotated clockwise. This is the opposite to a normal log volume control (A taper). It's necessary to have the right control law or taper in these situations to make sure the effect is evenly spread over the entire rotational range. The anti-log C taper is still not enough to avoid a jump at the high-gain end of the rotation. Alps make a special taper called 'RD', designed specifically for this application, but you have to buy thousands. All pots are noisy, most using carbon composition film. There is the moulded track type which is thicker but still a composition device, or the more modern conductive plastic, which is epoxy bonded carbon. These types are quieter.

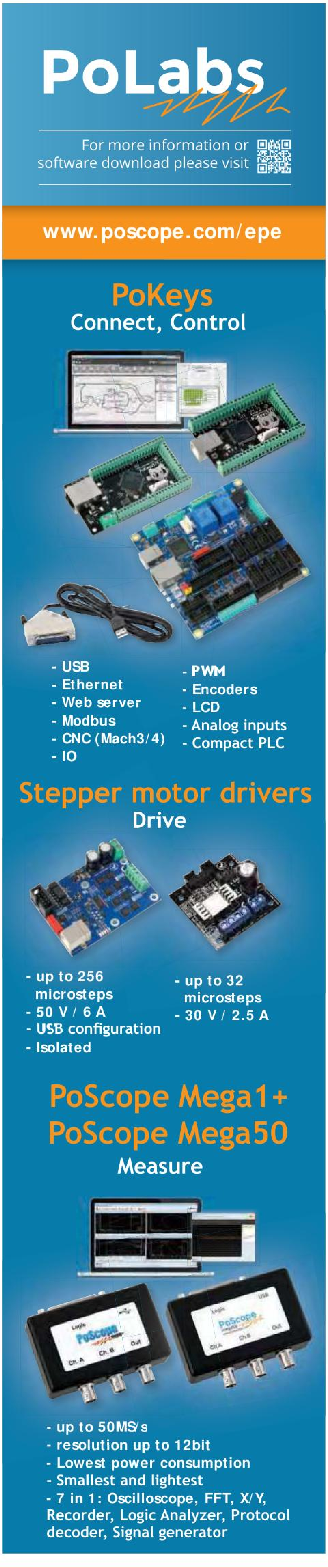
One thing I often do to reduce pot noise is to use a dual one wired in parallel. This does halve the resistance, but reducing the pot value down to 1-2.5kΩ gives a less abrupt jump at high gains at the expense of a higher minimum gain. I use a switched dual-gang 5kΩ pot and switch it out altogether for minimum gain – see Fig.6. If you are very fussy, you can go the route of API or Neve and have a gold-plated Elma switch with 1% metal-film resistors calibrated in equal dB steps.

Capacitors

Turning to capacitors and noise, plastic film types are the quietest because they have very low leakage currents. Where high capacitance is required and electrolytics have to be used, tantalum types (shown in Fig.7) have lower leakage than standard wet aluminium, especially where they have not been used for a while and they have to reform. X7R ceramic multilayer types are very poor; they actually act like piezo microphones themselves; ie, they are microphonic. Tap them, and they go 'ding'.

Next month

That's all for this month, next month we'll design and build the circuit.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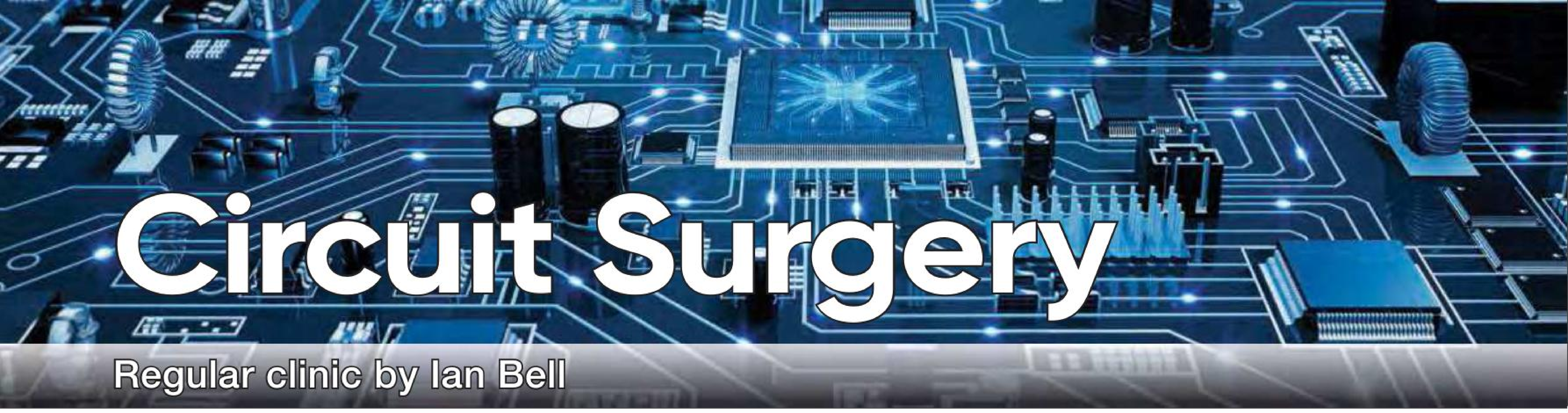


Circuit Surgery

Regular clinic by Ian Bell

Solving a circuit: iteration load lines and simulation

In the January issue of PE, a couple of articles were featured which mentioned load lines, and editor Matt Pulzer suggested a *Circuit Surgery* article looking at this topic.

A load line is a graphical means of solving what a circuit will do without having to perform detailed mathematical analysis. In this article we will look at load lines in the context of the various ways to solve non-linear circuits – specifically the diode-resistor circuit in Fig.1. This is a straightforward circuit – a forward-biased diode, that is a diode with current flowing in the direction indicated by the arrow shape of the diode symbol. Assuming we know some basic circuit theory, the voltage-current relationships for a diode and a resistor, and the diode's characteristic parameter values, then we might assume it would be easy to find an equation for current in the circuit in Fig.1. If there were two resistors instead of a diode and a resistor it would be easy with basic circuit theory; however, it turns out not to be so simple to 'solve' the diode circuit.

Before going into details of the diode circuit we will review the circuit theory we need and solve a two-resistor circuit as a point of comparison. Two of the key principles of circuit analysis are known as Kirchhoff's laws (which date from 1854). One law states that, 'the sum of currents *into* a junction in a circuit is zero (or total current in = total current out).' This also means the current through a set of components connected in series is the same in each component (the diode and resistor currents are equal in the circuit in Fig.1). The other law states that, 'the sum of voltages round any loop in a circuit is zero.'

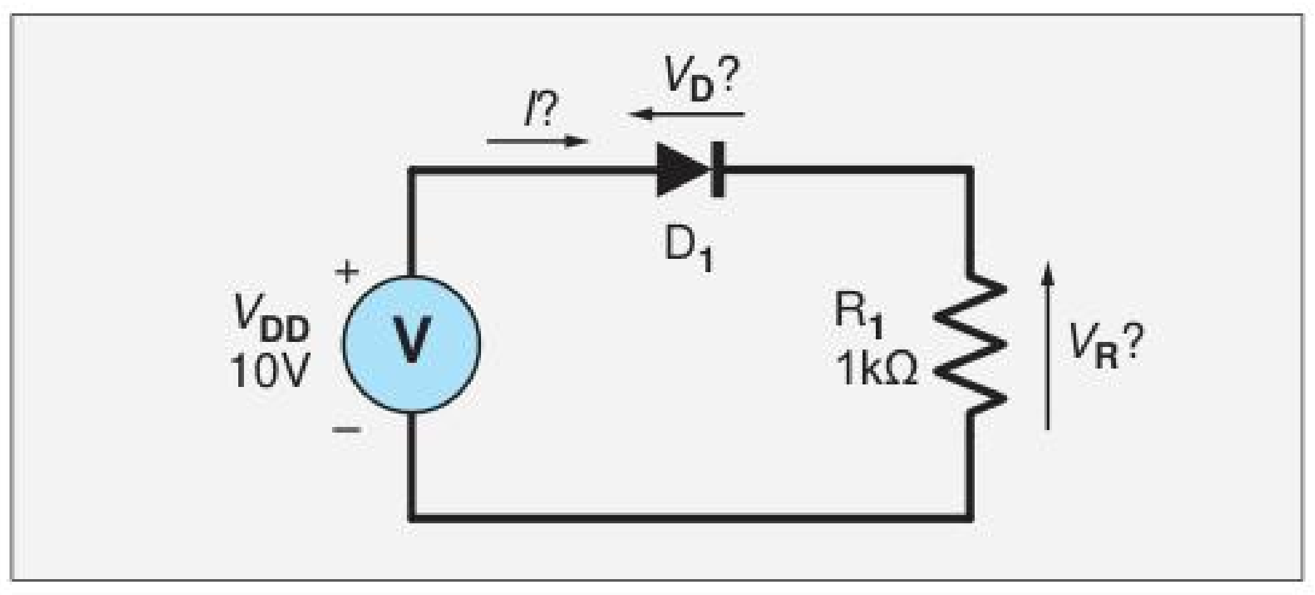


Fig.1. Diode-resistor circuit.

Simulation files

Most, but not every month, LTSpice is used to support descriptions and analysis in *Circuit Surgery*. The examples and files are available for download from the *PE* website.

Circuit laws and component models

Kirchhoff's laws deal with either voltage or current on their own. To fully analyse a circuit, we need to know the relationships between currents and voltages in the circuit. These relationships are described by the characteristic equations of each component. For our example, the characteristic equation for a resistor is $V = IR$, which many readers will recognise as Ohm's law. So, for example, for Fig.1, we can write: $V_R = IR_1$

Ohm's laws, and hence the characteristic equation for the resistor, was first obtained experimentally by Georg Ohm in the 1820s. It can also be derived from the fundamental physics of conductors, although historically this happened much later. For a real resistor, Ohm's law is an approximation, the resistance may actually change with applied voltage, and it will probably change with temperature, including that caused by self-heating of the resistor. Furthermore, resistors generate electrical noise, and Ohm's law only applies to the *average* current. The mathematical way we choose to represent a component is referred to as the 'model' of that component.

Most of the time, for resistive components that we use in circuits we can simply use $V = IR$ in circuit analysis. If choose to include other factors in our calculations (and do so correctly) we get a more accurate results at the expense of more difficulty and complexity. For manual calculation, too much complexity may make the process error-prone, or even intractable; and for computer-based analysis (circuit simulation), run times will increase with more complex models. As always in engineering, there are compromises – in this case between accuracy and complexity.

In the resistor characteristic equation $V = IR$ the R (the resistance) is referred to in general terms as a 'parameter' (or model parameter). All component characteristic equations will have one or more parameters. We can analyse a circuit algebraically using symbols for the parameters (eg, R_1, R_2… for the resistors), but if we need to know actual voltages and currents, we have to obtain the specific parameter values for every component.

Diode equation

In order to include semiconductor components, such as the diode in Fig.1, in circuit analysis we need a model; that is the characteristic equations for general analysis, and actual parameter values for specific calculations. We can use an understanding of semiconductor physics to derive a characteristic equation for a diode – like Kirchhoff's and Ohm's laws, this is well established theory. For an idealised case we get the following, relating the current through the diode (I_D) to the voltage across it (V_D):

$$I_D = I_s\left[exp\left(\frac{V_D}{V_T}\right) - 1\right]$$

This is known as the 'Shockley ideal diode equation'. V_T is called the thermal voltage. It is about 26mV at room temperature and is given by kT/e, where T is the junction temperature, and e and k are physical constants, the charge on the electron and Boltzmann's constant respectively. The key parameter for individual diodes is I_S – the reverse saturation current – which can vary over orders of magnitude, depending on the device and temperature, for example 10^{-14} to 10^{-10}A for silicon diodes (the default in LTspice is 10^{-14}A).

The exponential nature of the voltage-current relationship means that very little current flows for low forward voltages, but it increases rapidly with applied voltage so that the diode 'switches on' and conducts at around 0.6 to 0.7V. For conduction at or close to these 'on' levels the exponential term is much bigger than 1 and we can simplify the diode equation to:

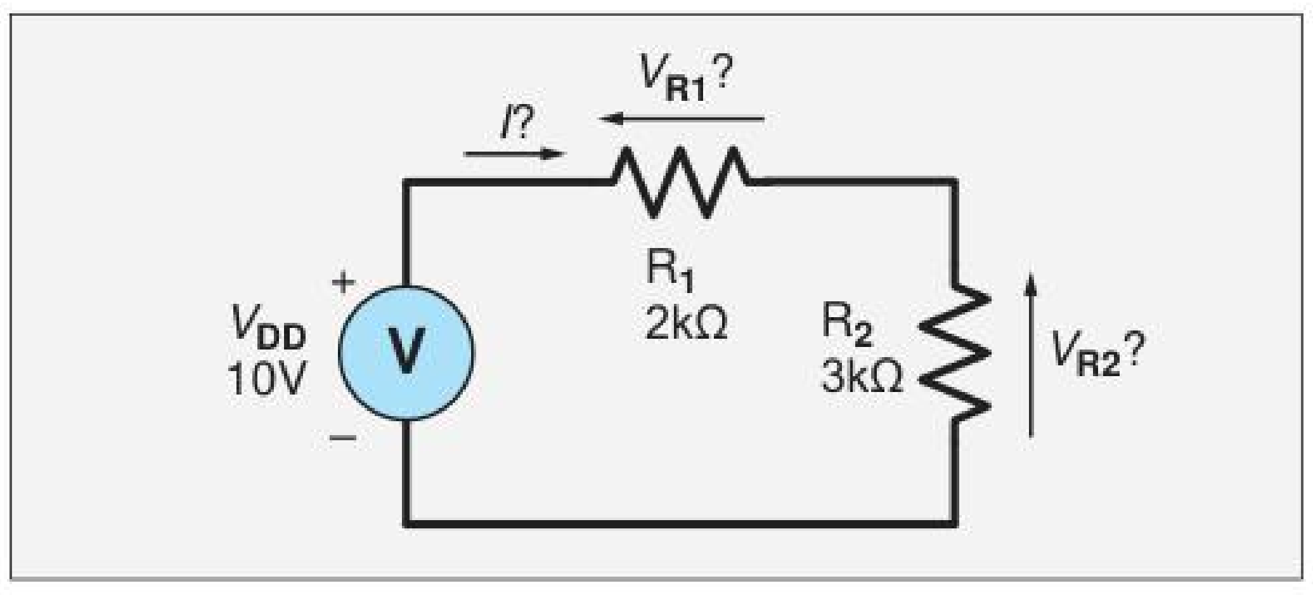


Fig.2. Two-resistors circuit.

$$I_D = I_s\, exp\left(\frac{V_D}{V_T}\right)$$

If we know I_D and want to find V_D we can rearrange this equation by taking natural logarithms (ln – the inverse of the exponential function) to produce:

$$V_D = V_T\, ln\left(\frac{I_D}{I_S}\right)$$

Two-resistor circuit

As noted above, before tackling the diode-resistor circuit we will analyse a circuit with two resistors (Fig.2). After that we will attempt to follow the same procedure for the diode circuit. To analyse the circuit in Fig.2 we can proceed as follows:

Current in R_1 is given by: $I = V_{R1}/R_1$
So $V_{R1} = IR_1$

Current in R_2 (in terms of V_{R1} and V_{DD}) is given by:

$$I = \frac{V_{DD} - V_{R1}}{R_2}$$

Eliminate V_{R1}

$$I = \frac{V_{DD} - IR_1}{R_2}$$

Solve for I

$$I = \frac{V_{DD}}{R_1 + R_2}$$

Using the component values, $I = 10/(2\text{k}\Omega + 3\text{k}\Omega) = 2\text{mA}$. Using $V = IR$ we also get $V_{R1} = 4\text{V}$ and $V_{R2} = 6\text{V}$.

Diode-resistor circuit

Now, let's attempt to follow the same procedure for the resistor-diode circuit in Fig.1. The current in a diode is given by: $I = I_S \exp(V_D / V_T)$, so $V_D = V_T \ln(I / I_S)$. Thus, the current in R (in terms of V_D and V_{DD}) is:

$$I = \frac{V_{DD} - V_D}{R}$$

Eliminate V_D

$$I = \frac{V_{DD} - V_T \ln(I/I_S)}{R}$$

The next step would be to solve the equation for I – to rearrange the equation to make I the subject, but unfortunately, we can't do this easily. Diode circuits produce transcendental equations which, in general, are difficult or impossible to solve. A transcendental equation is one that involves a transcendental function, which include the exponentials/logarithms we have here. A transcendental function is one which cannot be expressed in terms of algebraic operations – the name 'transcendental' refers to the idea that it 'transcends' or goes beyond algebra. Actually, it is not impossible to solve the diode-resistor circuit equation, but it requires some very advanced maths, specifically the Lambert W-function, which most people probably never encounter or use (see the Lambert W-function Wikipedia page if you want to know more).

Rule of thumb

If we cannot solve the circuit in Fig.1 by manipulating the circuit equations algebraically, what can we do instead to find the diode current? A simple answer, which is commonly used in quick circuit design calculations is to assume the voltage across the diode (the forward-voltage drop) is 0.7V. It is well known that for typical operating currents in most circuits the voltage across a forward-conducting standard silicon diode is likely to be in the range 0.6 to 0.8V; so 0.7V is often taken as the rule-of-thumb value to use. For other types of diodes, which might have different voltages (eg, LEDs) the forward-voltage drop is often stated on the datasheet, so we can use the same approach. In the resistor-diode circuit of Fig.1, if the supply is not too close to the expected diode voltage, the expected range of forward-voltages does not make much difference to the resistor current and so we can get a reasonable estimate just by assuming $V_D = 0.7\text{V}$. If we do this then we get $V_{R1} = 9.3\text{V}$ and $I = V_{R1}/I = 9.3/1000 = 9.3\text{mA}$ for the circuit in Fig.1.

The 0.7V rule of thumb gives us an approximate solution to the circuit, but it may not be very accurate. What can we do if we want to find a more accurate value? Choosing 0.7V is basically an informed guess about what is happening in the circuit. Having made such a guess, we can use the diode equation to find the corresponding current and hence the resistor voltage (V_{R1}) with this current flowing through it. We can then add the resistor and diode voltages, which should equal the supply voltage (if not, Kirchhoff's voltage law is not satisfied).

Guessing game

If our implied supply voltage is wrong, we can make a new, hopefully better, guess – for example, if the implied V_{DD} we calculated is too high, we can reduce the assumed diode voltage a little (eg, guess 0.68V instead of 0.7V) and see if that improves things. We can keep on guessing and refining our diode voltage value, recalculating the current and implied V_{DD}, and guessing again, getting closer and closer to the correct value. Formally, this guessing process is referred to as an iterative solution to the circuit. Here is an example for Fig.1 in which we will use $I_S = 1.0 \times 10^{-14}$A and $V_T = 2.585$mV (for a temperature of 27°C):

Guess: $V_D = 0.7\text{V}$, so $I = I_S \exp(V_D / V_T) = 5.70\text{mA}$ (diode equation)
Thus: $V_{DD} = V_R + V_D = 6.400\text{V}$ – too low – so increase V_D guess to 0.725V

With: $V_D = 0.725\text{V}$, $I_D = 4.986\text{mA}$ (from the diode equation)
Thus: $V_R + V_D = 15.711\text{V}$ – too high – so decrease V_D guess to 0.7125V

With: $V_D = 0.7125\text{V}$, $I_D = 9.242\text{mA}$ (from the diode equation)
Thus: $V_R + V_D = 9.955$ just too low – so increase V_{DD} guess to 0.7126V

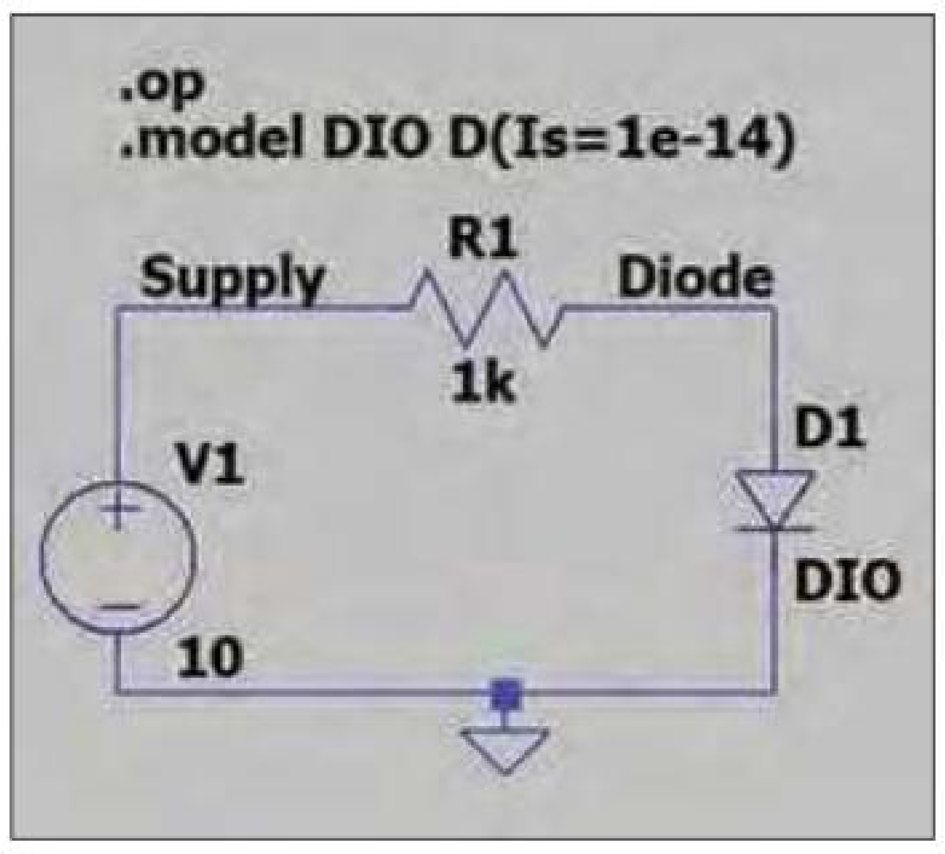
With: $V_D = 0.7126\text{V}$, $I_D = 9.278\text{mA}$ and $V_R + V_D = 9.990\text{V}$

This final result implies the supply is 9.990V rather than 10V, a 0.1% error. We could continue to add more significant figures, but we have to stop at some point when the result is 'close enough' – how we decide what is close enough depends on what we need in terms of accuracy.

Numerical methods

The guess and recalculate process we have just used is a crude manual version of what simulators such as LTspice are doing when they solve a circuit. The approach to finding the next guess is more sophisticated than the 'think of a number' approach implied above. The mathematical techniques involved are referred to as 'numerical methods', or 'numerical analysis' and involve numerical approximation rather than symbolic manipulation. These have a long history. For example, the Newton-Raphson method, which can be used by circuit simulators, is derived from work by Isaac Newton and Joseph Raphson in the 17th century. Other numerical methods are older still, going back to the earliest mathematical writings on Babylonian clay tablets.

As with our manual iteration, circuit simulators must decide when to stop a given calculation – when it is 'close enough' – referred to as convergence in simulator terminology. SPICE simulators measure convergence in a couple of ways: the difference between iterations and the degree to which Kirchhoff's current law has been met. If the difference between iterations is small enough it implies the solution has been reached and new steps will not get significantly closer. In



```
.op
.model DIO D(Is=1e-14)
```

Fig.3. LTspice schematic for circuit in Fig.1.

our manual iteration above we checked the implied supply voltage – effectively checking Kirchhoff's voltage law has been met – SPICE's checking of the current law is similar – if the numerical values of current throughout the circuit are in compliance with the law sufficiently closely then the solution is likely to be good. SPICE uses a number of numerical values to decide when convergence has occurred, for example, `abstol`, the absolute current error tolerance and `reltol`, the relative error tolerance. These values can be changed via user options, for example in LTspice via the SPICE tab of the Control Panel.

Simulation example

Fig.3 shows the circuit from Fig.1 drawn as an LTspice schematic and includes the diode model statement to set the I_S parameter to 1×10^{-14}A. This is not strictly required, as it is the same as the default, but illustrates how this key parameter can be set. We run an operating point analysis in LTspice (`.op` directive) to obtain the current and voltages. LTspice simulates at a default temperature of 27°C so we should get similar results to our manual calculation. The results, which are shown below, are close to our calculation.

```
       --- Operating Point ---
V(diode): 0.712763     voltage
V(supply):10           voltage
I(D1):     0.00928724  device_current
I(R1):    -0.00928724  device_current
I(V1):    -0.00928724  device_current
```

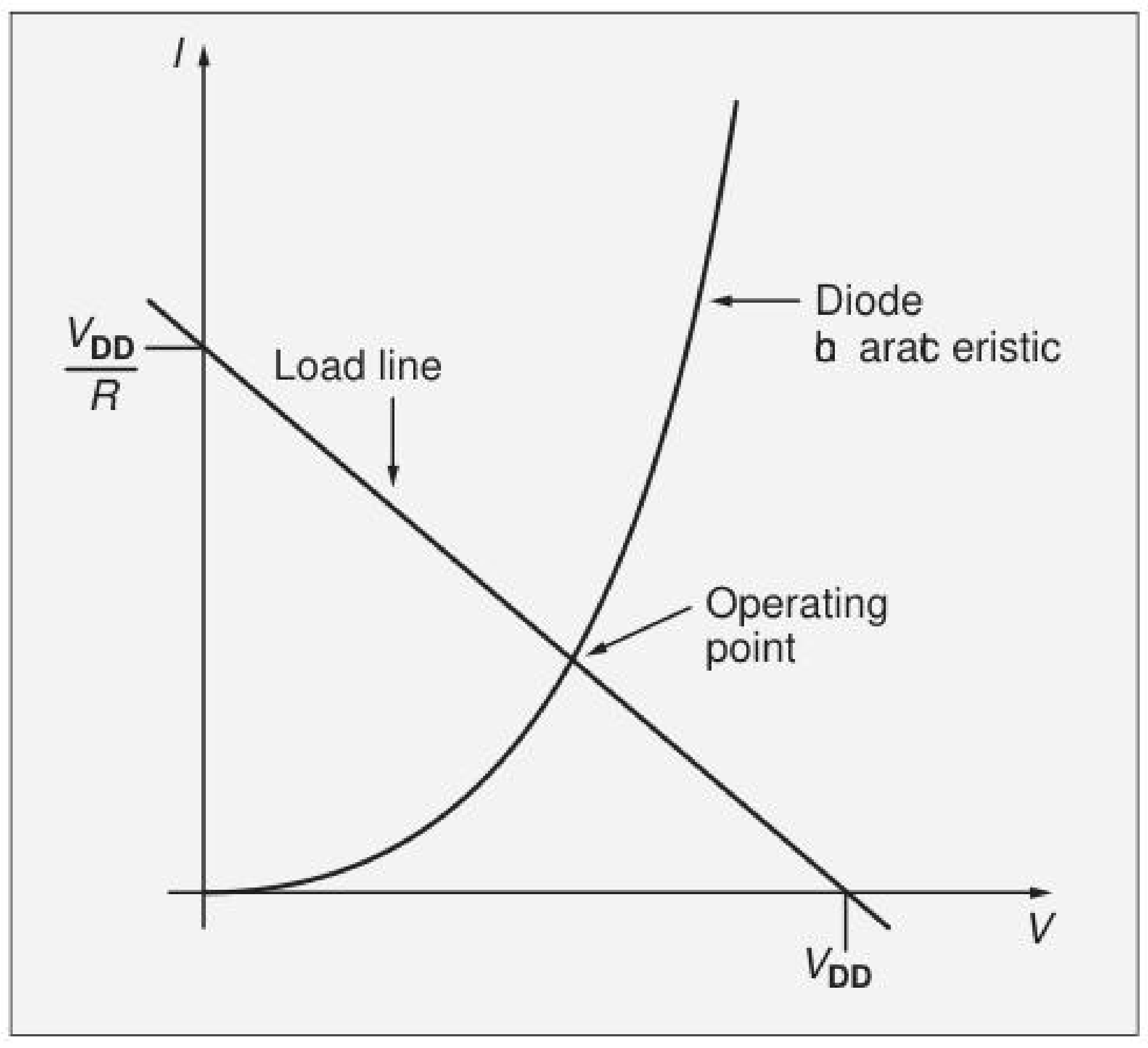


Fig.4. Load line for a diode-resistor circuit.

Loads lines

An alternative approach to iterative calculation, which does not use a simulator, is to plot a load line graph. This is a plot of the diode and resistor characteristics on the same axes – the point where the two traces cross is the solution to the circuit, also referred to as the operating point. The term 'load line' comes from the idea that we have an active component (a diode or transistor) controlling the signal (output) to a load (often a resistor). As we have seen, circuits such as that in Fig.1 cannot be easily solved using algebra, the load line is a graphical approach to solving the circuit, which does not need a full algebraic solution.

For a load line graph of the diode-resistor circuit (Fig.1) we plot on the same graph (see Fig.4) the diode characteristic:

$$I_D = I_s\, exp\left(\frac{V_D}{V_T}\right)$$

And the resistor current:

$$I = \frac{V_{DD} - V_D}{R}$$

The diode characteristic trace is simply a plot of the diode's current vs. voltage relationship. The resistor current trace – the load line – is a straight line because a resistor has a linear current-voltage relationship. The trace is the opposite way round to plotting a resistor's current *vs.* voltage relationship on its own because we are using the diode voltage as the axis – increasing V_D decreases the resistor voltage (together they add up to V_{DD}) and hence decreases the resistor current. The load line is easy to draw because it crosses the axes at the $I = 0$ and $V_D = 0$ points, which can easily be found from the above equation as $V_D = V_{DD}$ and $I = V_{DD} / R$ respectively (see Fig.4).

Plotting a load line manually on graph paper specifically to solve a circuit like Fig.1 is probably too much effort to be worthwhile, but load line graphs like Fig.4 are useful for visualising the behaviour of circuits. We can see how changing the resistor affects the operating point and how different operating points will change the effect of small variations of diode voltage on diode current. Diode load line graphs are often drawn with some artistic license when used for general discussion of circuit behaviour – so that the shape of the diode curve can be seen together with the full load line (eg, Fig.4). To get a graph looking like Fig.4 would require a supply of around 0.8V and a resistor around 80Ω – not really typical values.

Load lines in LTspice

Fig.5 shows the actual load line graph for the circuit in Fig.1, obtained using LTspice. It is not usual to plot a load line using SPICE because, as we have seen, the simulator can solve the circuit operating point directly. However, Fig.5 nicely illustrates the fact that the diode has an almost constant voltage of around 0.7V over a wide range of operating currents when plotted on a voltage axis covering the entire supply range (the diode curve is almost a vertical line).

Fig.6 shows the same results plotted over a small diode voltage range close to 0.7V. Here we can see the diode

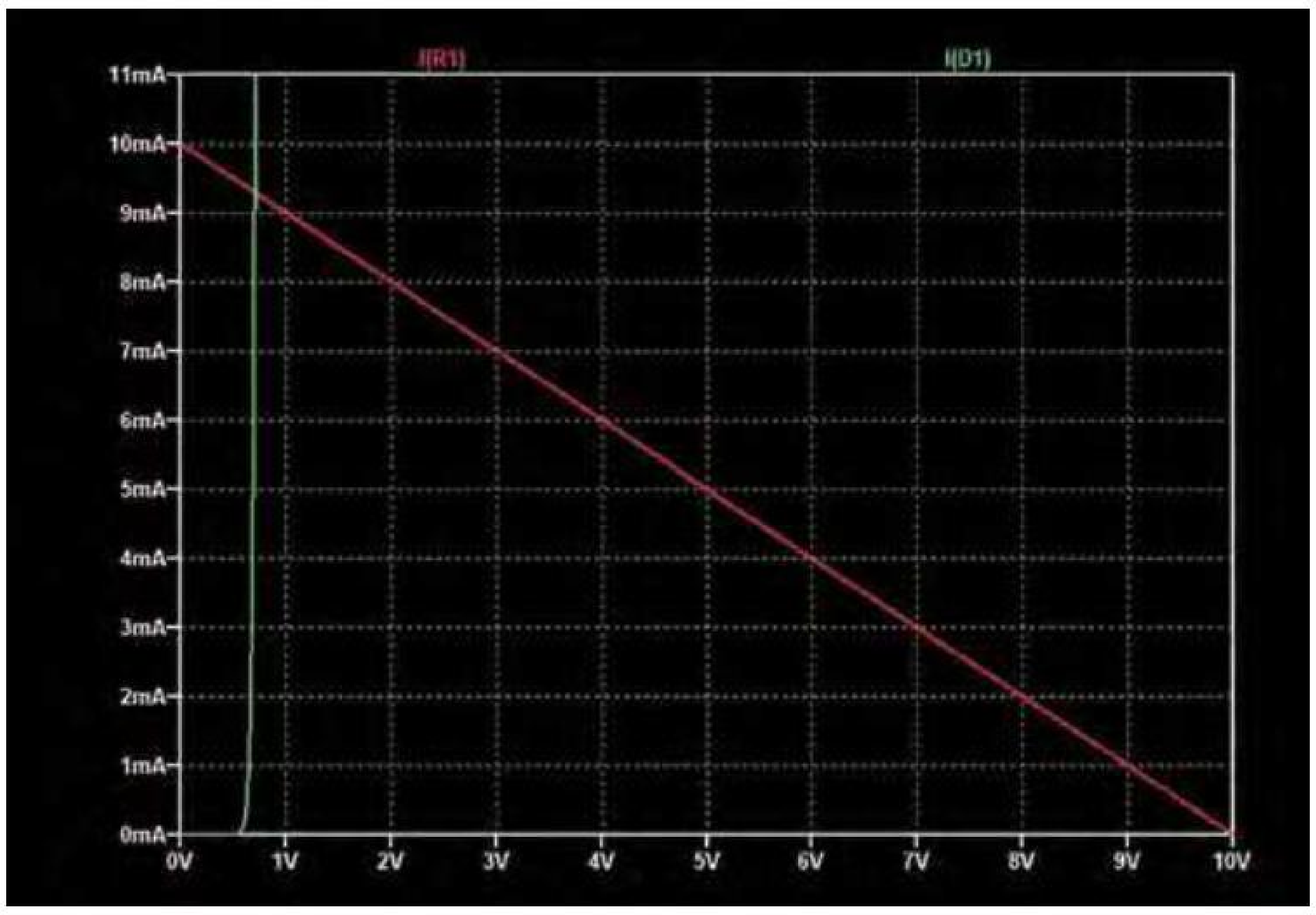


Fig.5. Actual load line graph for the circuit in Fig.1.

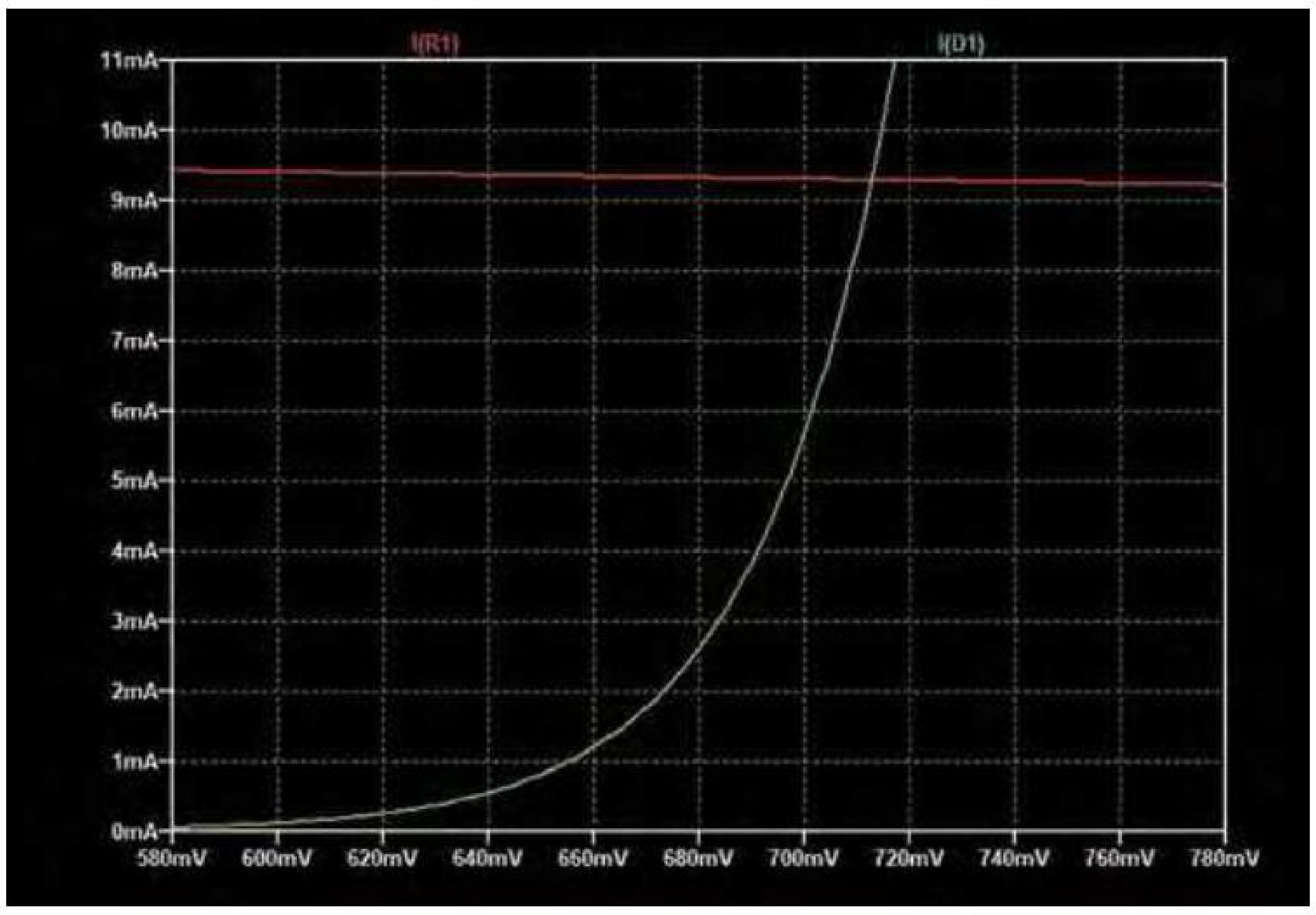
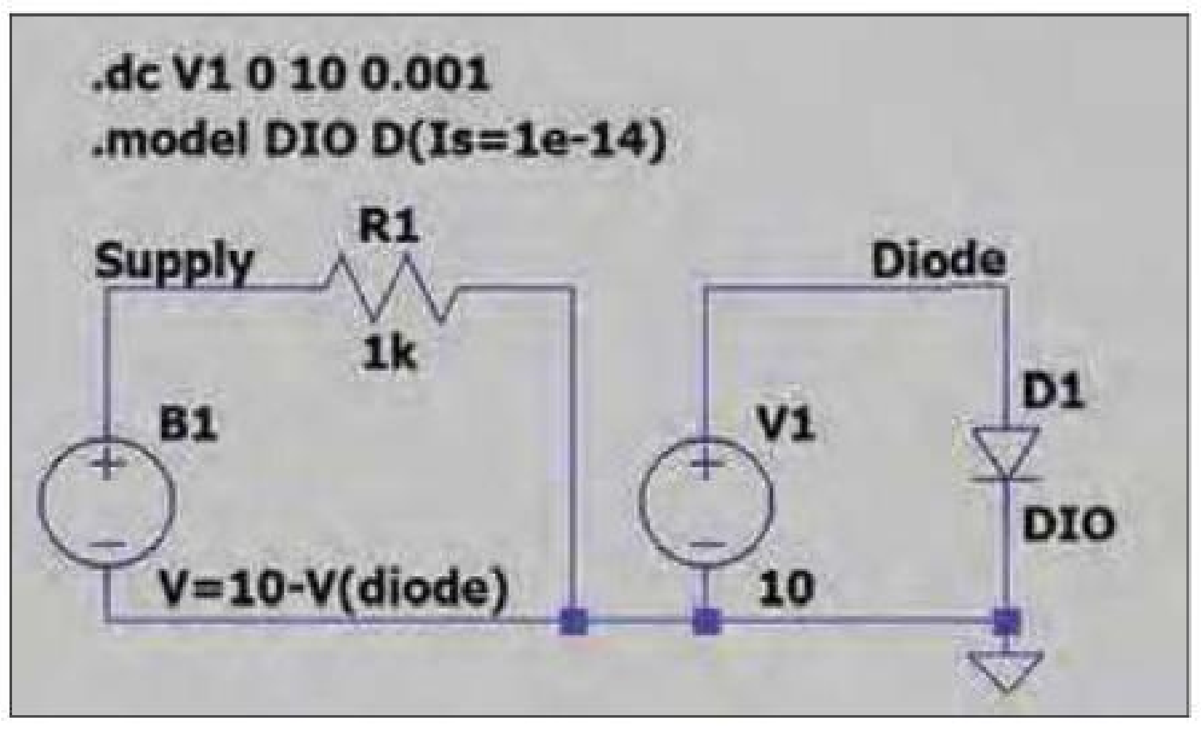


Fig.6. The load line results (Fig.5) zoomed to show the diode characteristic shape.



```
.dc V1 0 10 0.001
.model DIO D(Is=1e-14)
```

Fig.7. LTspice circuit used to plot load line graphs (Fig.5 and Fig.6).

characteristic curve shape more clearly. Note that the resistor current is almost constant over this range (horizonal line). This illustrates that with typical supply voltages of several times the diode forward voltage the resistor current will not change much for different diode voltages. This brings us back to the starting point of our discussion on this circuit where we simply assumed the diode drop was 0.7V and consequently obtained a current of 9.3mA. If we zoom in more and use the cursor, we find that the point where the curves cross closely matches the operating point simulation results given above.

A load line graph considers the component currents independently over the entire supply range, so we can't use the circuit in Fig.3 directly to plot it. The LTspice schematic in Fig.7 was used to obtain the graphs in Fig.5 and Fig.6. A linear DC sweep analysis was used to step the voltage from the V1 voltage source from 0 to 10V in 0.001V steps. This voltage is applied directly across the diode so we can obtain the characteristic current. The small steps are useful as we are going to zoom in on the steep diode curve. It should be noted that we get some unfeasibly large diode currents from simulating the diode on its own over the 0 to 10V range – the simulator is not limited by maximum power dissipation or supply capabilities! In the actual circuit the maximum current in the diode is limited by the resistor.

The resistor voltage is obtained by subtracting the currently applied diode voltage (`V(diode)`) from the 10V supply voltage (as `V1` is swept) using a behavioural voltage source (B1). Behavioural sources allow us to write equations for a source's output in terms of other circuit parameters and were discussed in detail in the August 2020 *Circuit Surgery*.

Transistor load lines

To extend the load line theme a little, Fig.8 shows a load line for the basic BJT common-emitter circuit in Fig.9. As with the diode circuit, we simulate the transistor characteristics and the load resistor separately to obtain the load line plot – the circuit used is shown in Fig.10. We assume the transistor has been biased with a base current of 40µA but have not specified how this was done. Like the diode-resistor load line, the load line for this circuit intersects the axes at the supply voltage (5V) and the current which would flow in the resistor if it was connected across the supply (5/300 = 16.7mA).

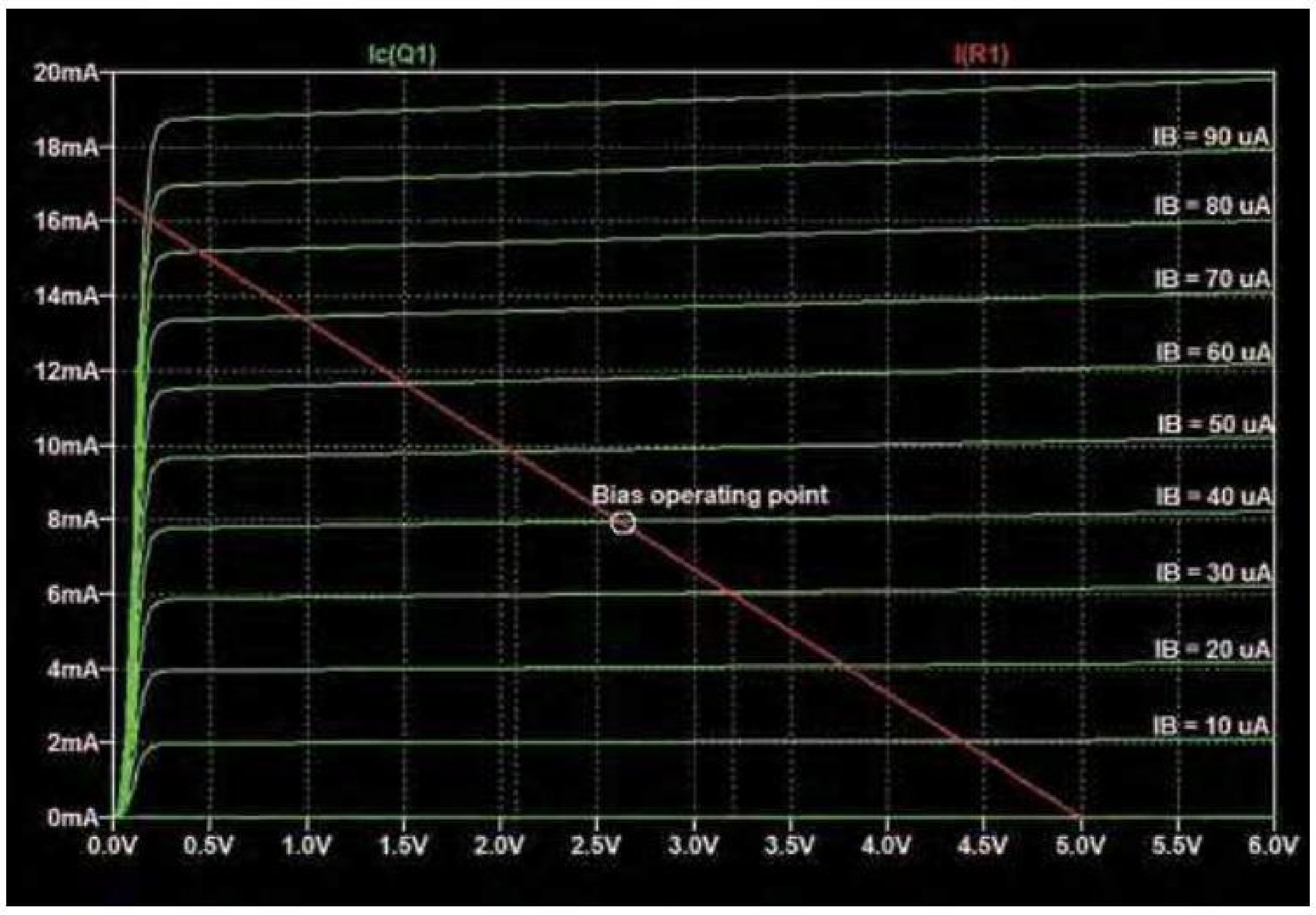


Fig.8. Load line for the BJT circuit in Fig.9. The plot shows the variation of collector current (I_C) with collector-emitter voltage (V_{CE}) at various base currents (I_B). The circuit's operating point moves along the load line as base current varies and is at the bias operating point with no signal.

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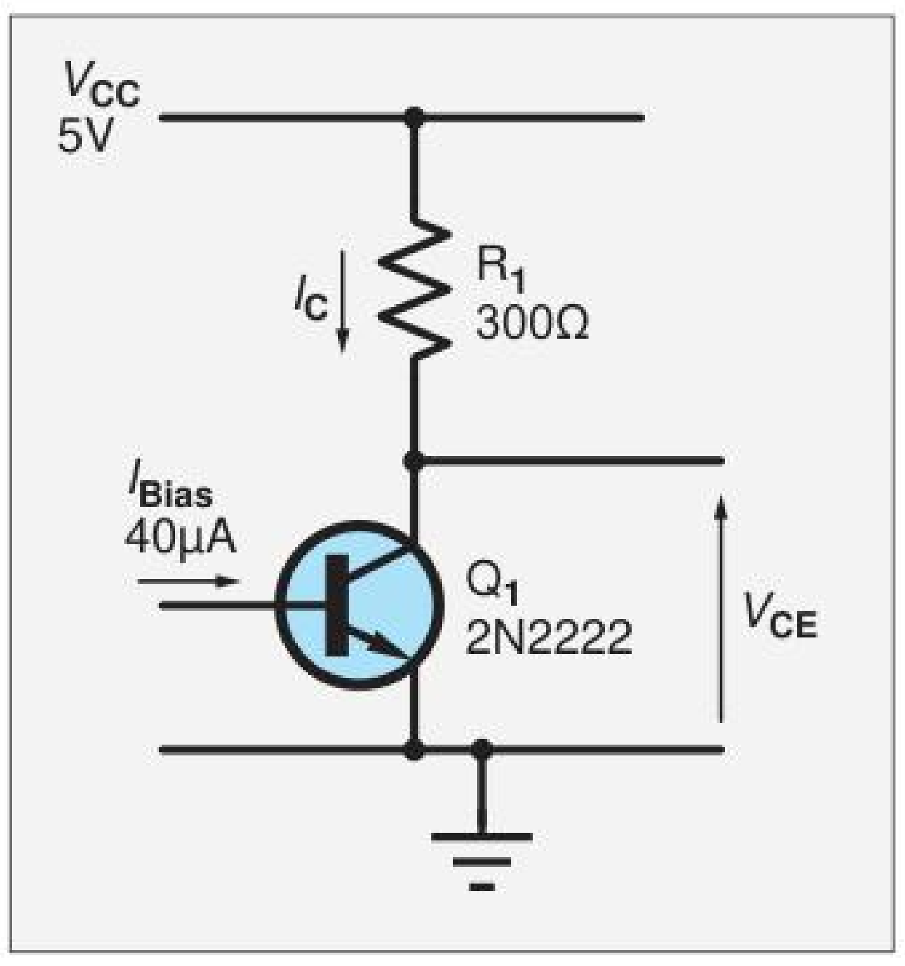
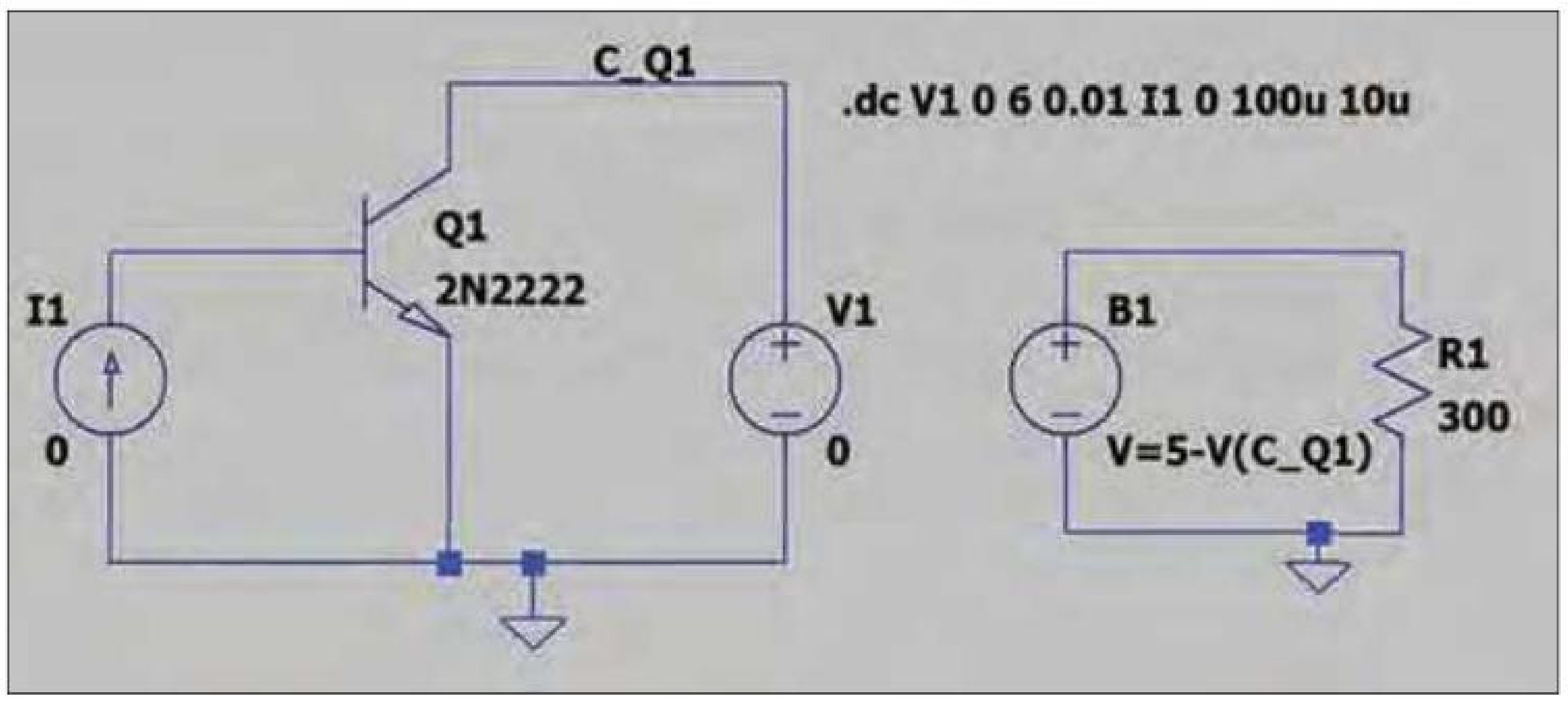


Fig.9. Basic BJT common-emitter circuit.

The operating point of the circuit is the point where the load line intersects the transistor output characteristic (I_C *vs.* V_{CE}) curve corresponding with the base bias. Fig.8 shows that for this example the output voltage would be around 2.6V with no signal. If the transistor was amplifying a signal, then the base current would vary accordingly. The load line provides an easy way to see how the output voltage would vary – the operating point moves along the load line as the base current changes. So, for example, if the input signal caused the base current to vary from 30 to 50µA then the output voltage would vary from about 2.1 to 3.2V. A similar example was discussed for a 2N2700 MOSFET circuit in Mike Tooley's *Kick Start* article in the January 2021 issue.



```
.dc V1 0 6 0.01 I1 0 100u 10u
```

Fig.10. LTspice schematic used to obtain the load line graph in Fig.8.

Practically Speaking

Hands-on techniques for turning ideas into projects – by Jake Rothman

Restoring old equipment – Part 3

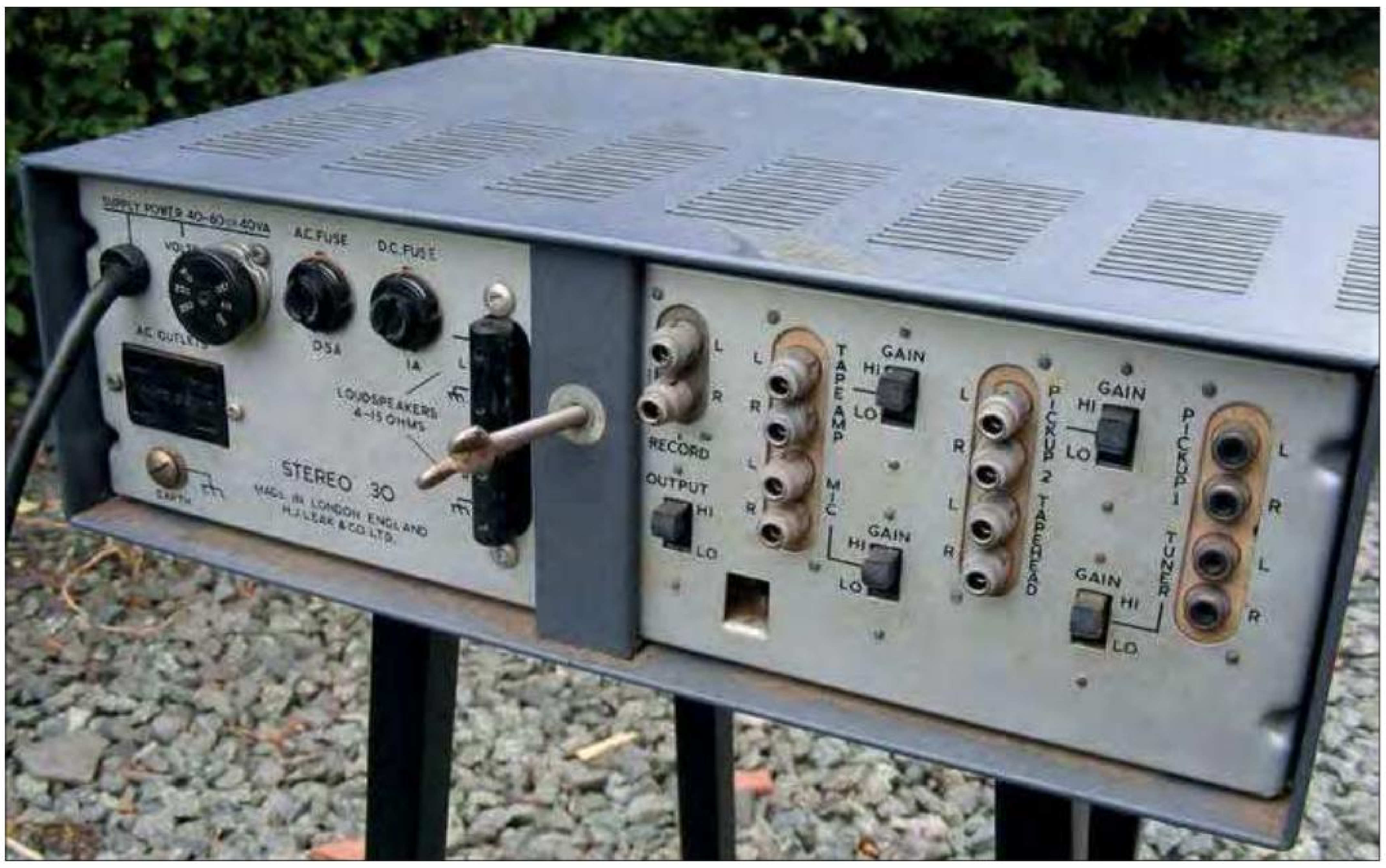


Fig.16. Easy servicing was an important criterion for old equipment. Full access by undoing one thumb screw and sliding off the sleeve – unbelievably convenient compared to modern designs.

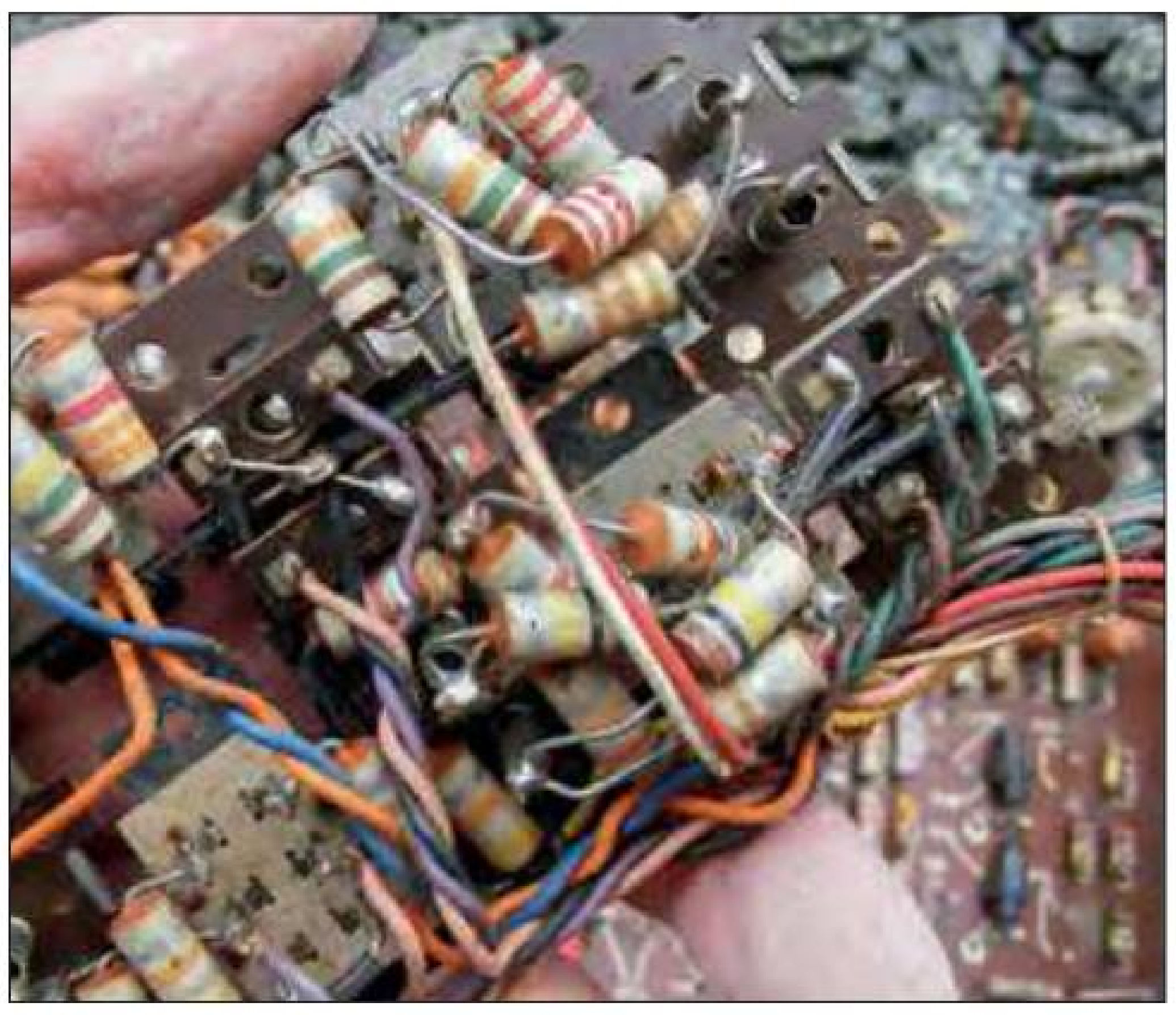


Fig.19. Complex wiring on the input sockets. I bypassed the switches because they couldn't be replaced.

Last time, we introduced the famous Leak Stereo 30 amplifier, an important milestone in British Hi-Fi history. This month, we'll move on to switches, components and the first application of power.

You only need to undo one thumbscrew (shown in Fig.16) to get inside the Stereo 30, allowing the metal cover to be slid off. Both sides of the PCB are then accessible. This must be a world record in simplicity. Some Japanese amplifiers require about 40 screws to be removed.

The front panel can be detatched by first taking off the knobs by loosening their grub screws and then undoing the pot nuts with a 0.525-inch across-flats pot-spinner, as shown in Fig.17. I had to do this to gain access to the front panel slider switches and then bend back the corner of the drop-damaged front panel (Fig.18).

Dodgy switches

A constant problem on these amplifiers are the black Cinch slide switches which use plain copper contacts. These fail open-circuit as they oxidise, effectively forming copper-oxide rectifiers. The rubber behind the sliding contacts can sometimes shrink and go hard, reducing the wiping pressure. The signal goes through two of them: gain switches on the back and the tape monitor switch on the front.

Access on the Leak is not all perfect however, there is some awful 'spag' (point-to-point) hard wiring around the rear input sockets and switches (see Fig.19). They had been wired after they had been screwed in; maybe the designers thought they would last forever. As usual, the switches had failed. I had to remove the big smoothing capacitors to reach them. Even then, I still couldn't get them out, so I ended up bypassing them out of circuit. The phono input has to be set to high sensitivity anyway for (phono/turntable) magnetic cartridges. Nobody uses high-output ceramic or crystal ones anymore – are they even made?

Getting to the front switches was also a battle. I found after removing the front panel bezel and knobs that they were riveted in. I can't stand rivets, they may be good for aircraft wings, but they make it difficult to replace components because they have to be drilled out. This tedious procedure is shown in Fig.20. I then replaced the rivets with M2.5 countersunk screws, countersinking the holes first.

The switches can be disassembled by unbending their tabs with side cutters. There is no need to disconnect them. The dirty contacts can then be filed clean with a fine file or sandpaper (Fig.21).

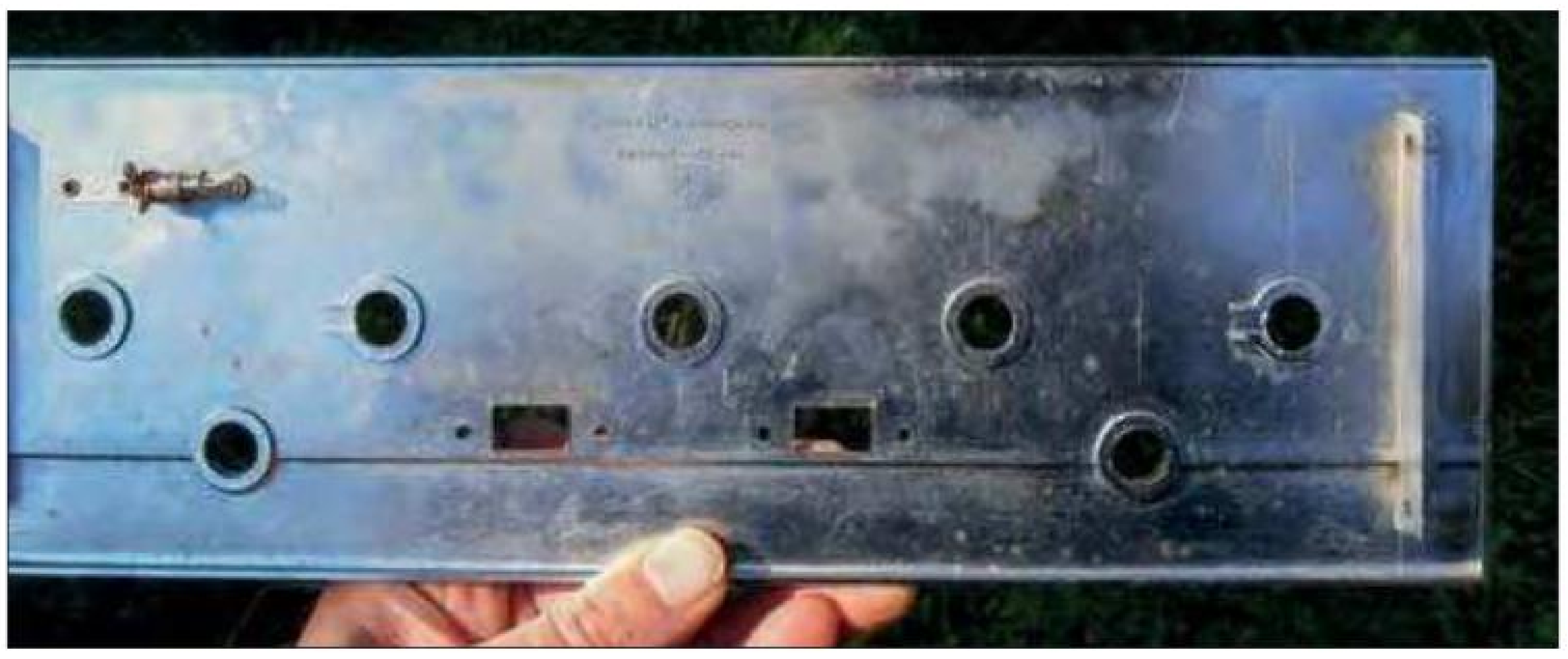


Fig.17. The diecast chromed front panel from my eBay Stereo 30.

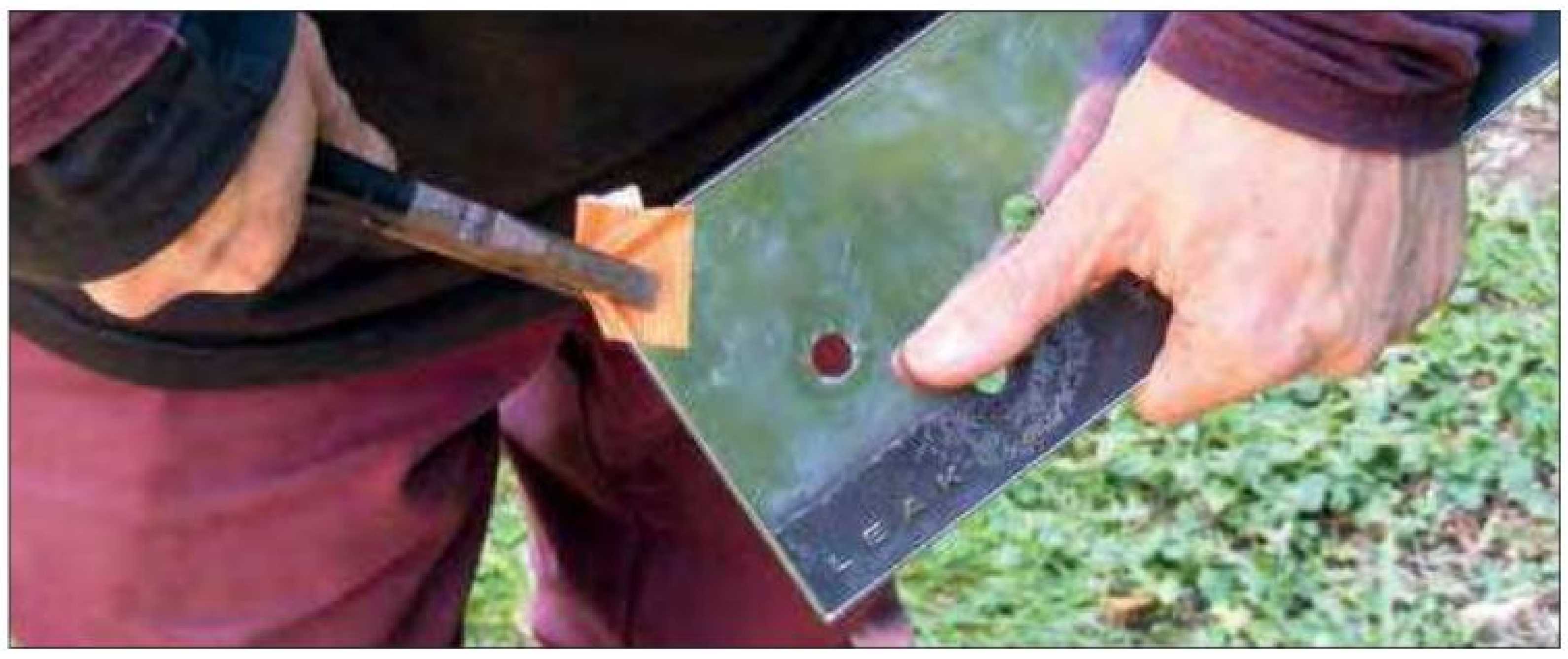
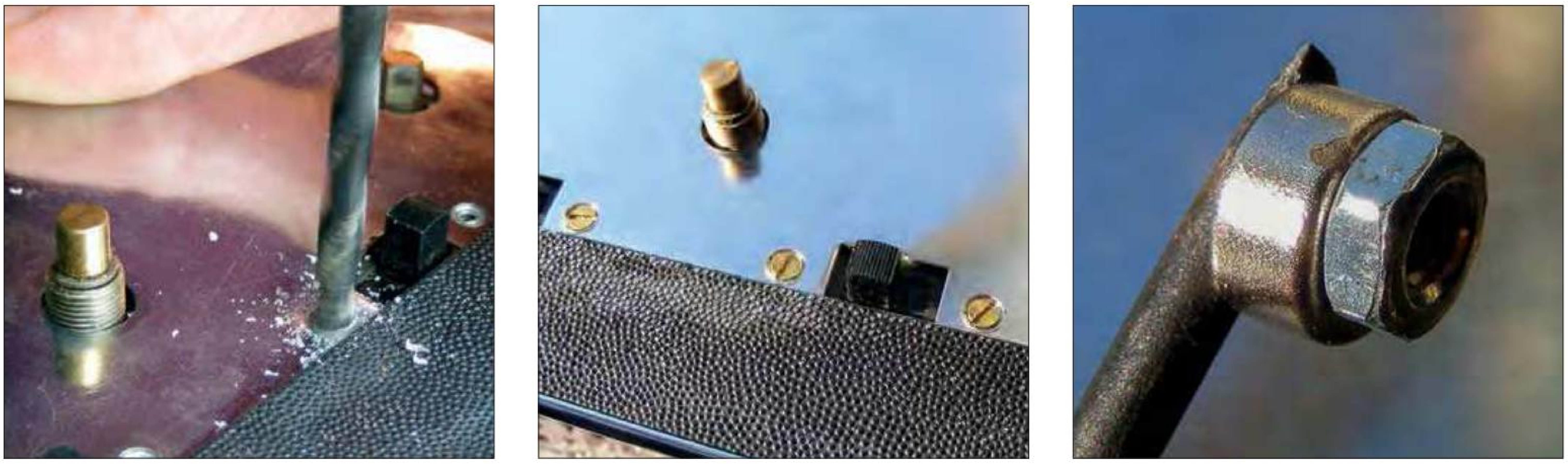


Fig.18. Bending the front panel – note tape to prevent scratches.



Figs.20. a) Rivets have to be drilled out to get to switches. The drill has to be a bit bigger than the rivet head; b) The rivets are replaced with M2.5 countersink bolts; and c) Fitting the nuts is tricky; use a small rare earth magnet on a screwdriver to position them.

Seal them quickly with contact lubricant such as Contralube (Fig.22). This trick is often needed for wave-change switches on old radios. If you have no luck with such a repair, C&K do a suitable switch, the S202031SS03Q from Mouser. Rotary switches are generally very reliable, but give them a good squirt with Super Servisol 10 switch contact cleaning lubricant while the front panel is off and all the contacts can be accessed.

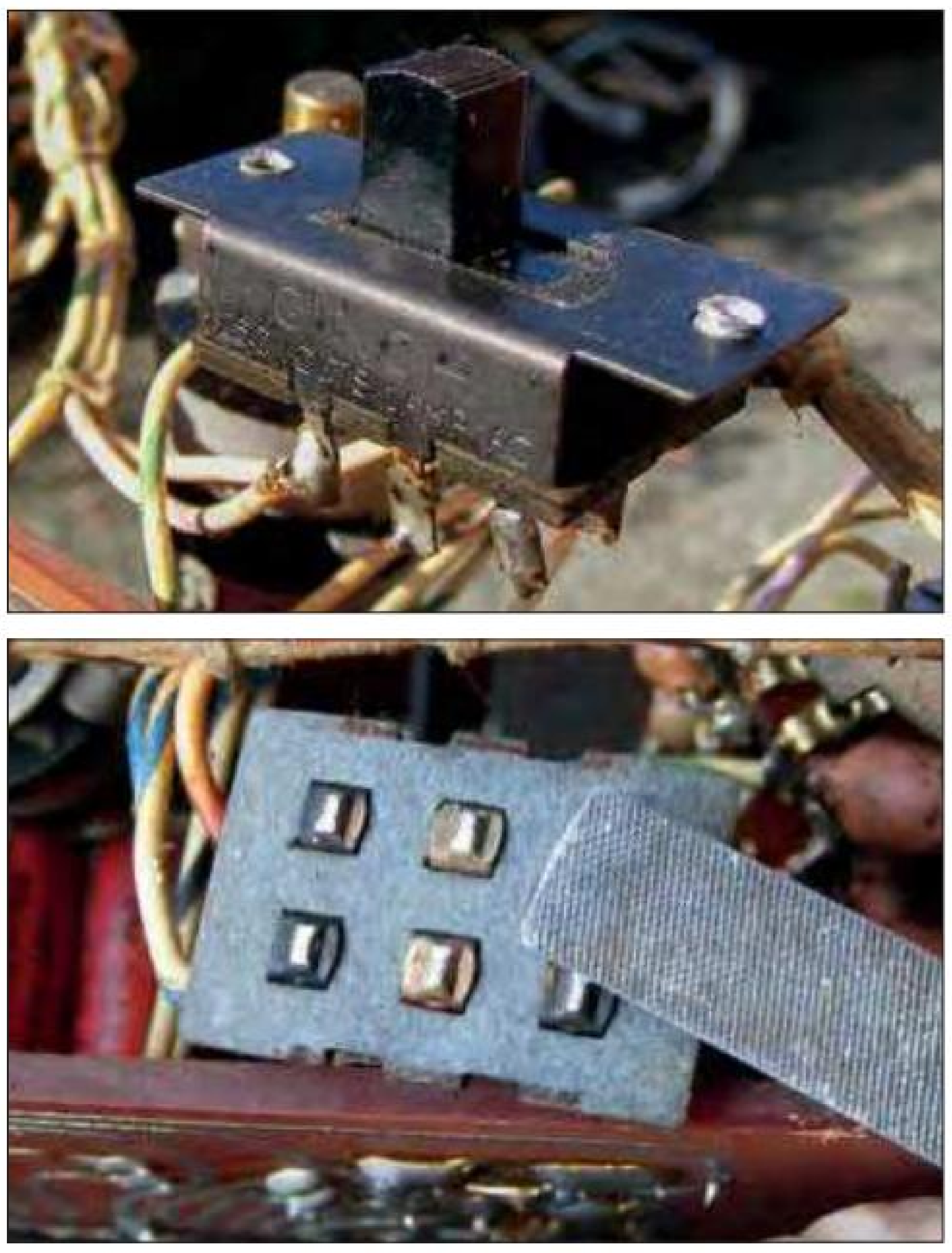


Fig.21. a) (top) The troublesome Cinch switches. Take the top metal part off by bending up tabs on back; b) (bottom) The blackened contacts of the switches are *gently* filed to reveal clean metal.

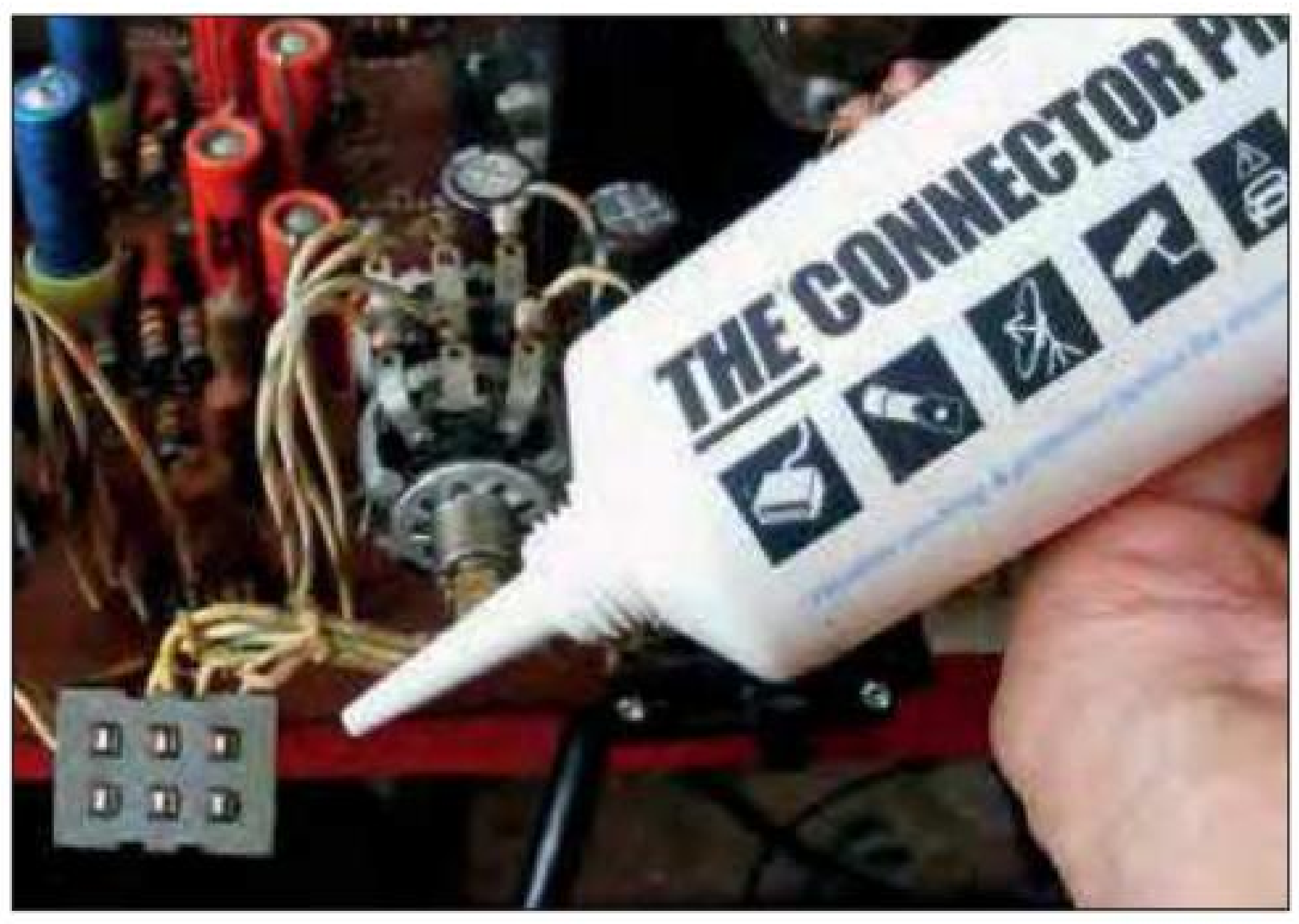


Fig.22. Contralube is applied to the contact to stop them oxidising again. This stuff glows under UV light to aid even application.

The rivet/bolt issue above neatly demonstrates the restorer's eternal dilemma – do I 'destructively improve' or attempt to preserve an inferior original aspect of a design? It applies to the restoration (or preservation) of everything – from medieval timber tithe barns to early computers and vintage cars. Only you can decide for yourself what to leave as is, what to restore to original spec and where to improve with modern technology. There is no right answer, and it very much depends on what you are restoring, the availability of spare parts, up-to-date safety thinking and why you are restoring it in the first place.

Tape-monitor switch

It is possible to bypass the preamplifier and feed a signal directly to the power amplifier input by switching the tape-monitor switch on the front to 'on' (left-hand side). The signal is fed into the tape replay input sockets, where it then goes straight to the volume control. Unfortunately, this is through another Hi/Lo sensitivity switch which has to be shorted out. Bypassing the preamplifier noticeably improves the distortion and high-frequency response. This is the best way to use this amplifier with a digital source, such as a CD player or computer.

Hidden history

I was pulling around the cable loom dealing with the switches when I noticed some pencil writing behind it on the chassis. It said '158-4-65' followed by what looked like Harold Leak's signature (see Fig.23). I guess the '158' was the serial number, quite an early one then.

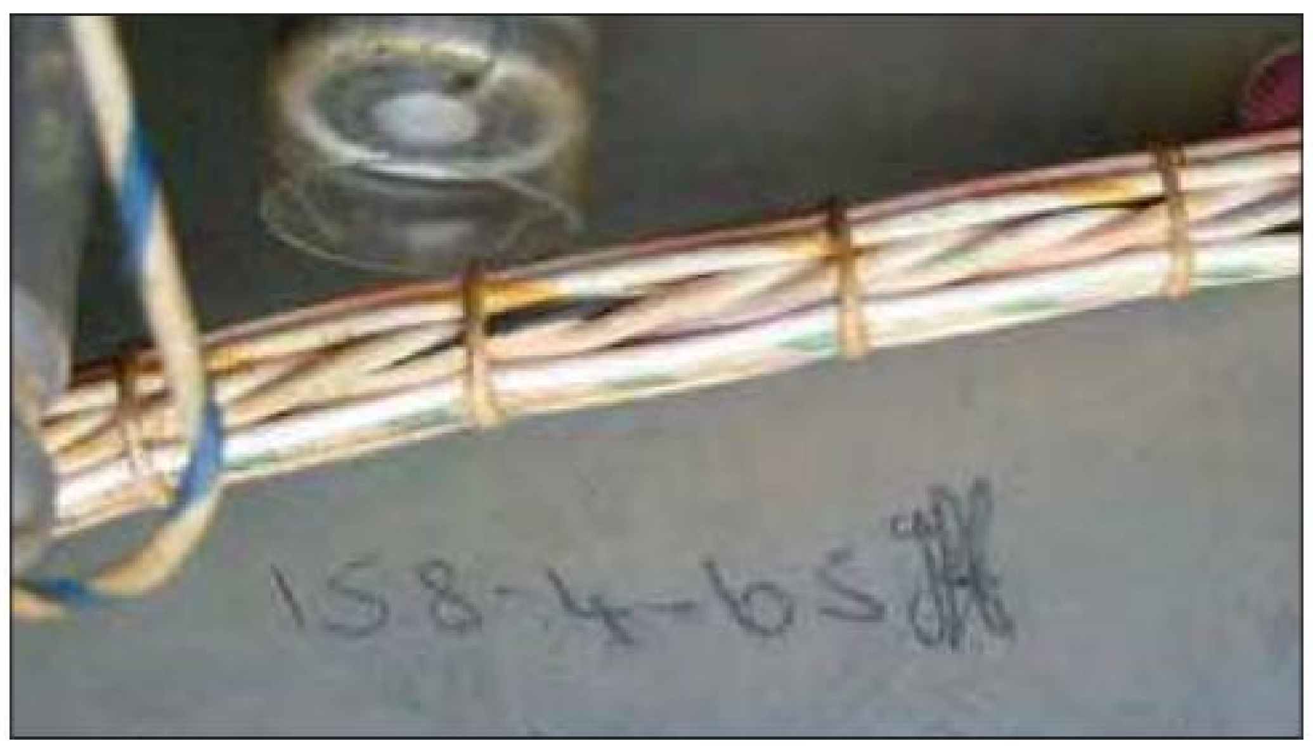


Fig.23. Signed by Harold Leak?

There was no serial number on the back of the unit. Looking at the eBay unit, it had a proper serial number plate on the back number – Z/18777 – and it was also written in the same place with another signature, which looked like 'J Quinn'.

Corrosion

The phono connectors on old amps such as this one are often badly corroded, as shown in Fig.24. These can be replaced with gold-plated ones, but it is a difficult job, necessitating the machining of new mounting plates. However, although they often look bad, after a good scrubbing with wire wool, they seem to work fine (Fig.25).

Sometimes though, radical surgical excision is necessary! I had to do this with

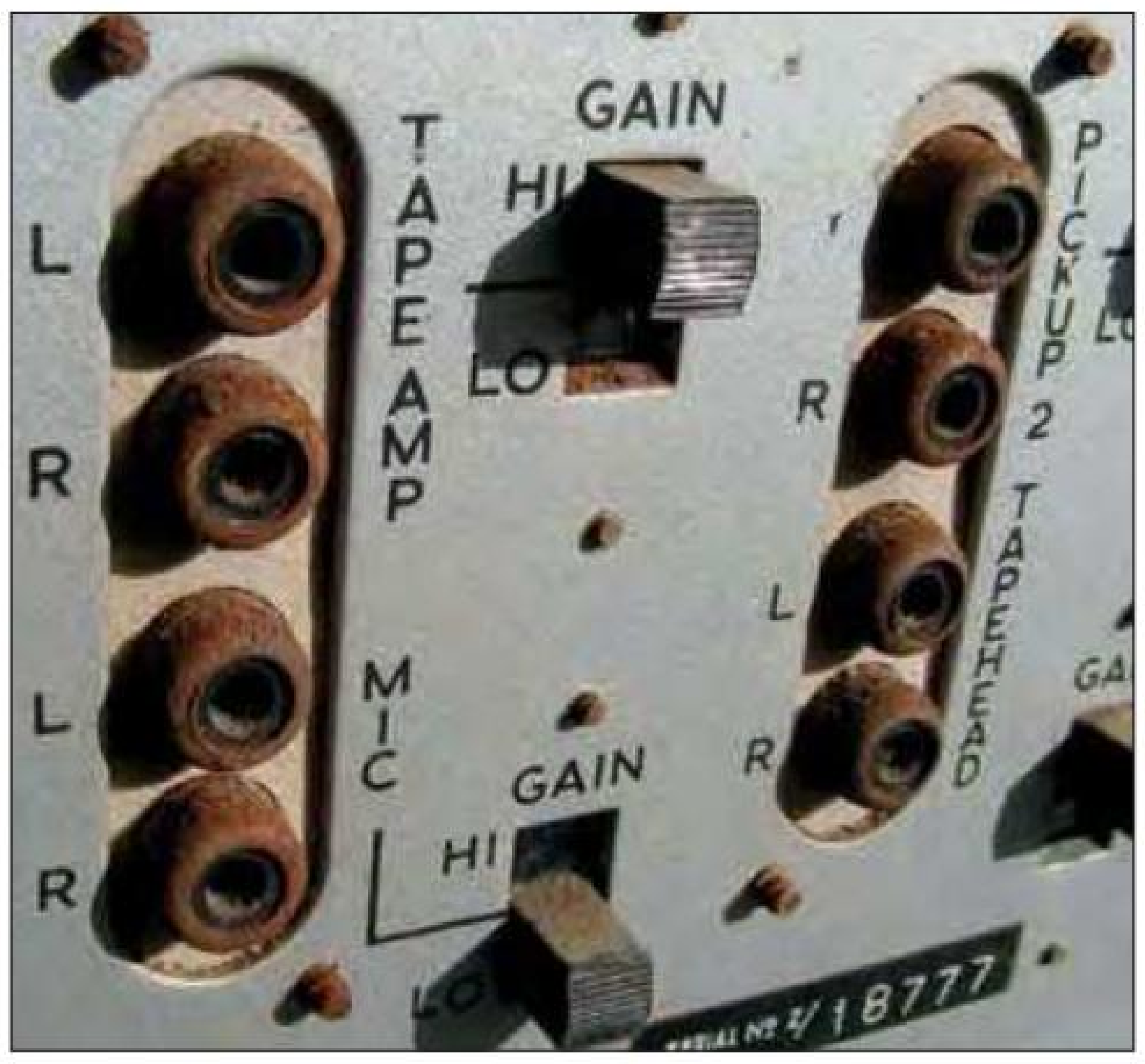


Fig.24. These input sockets are badly corroded, and need to be replaced or thoroughly cleaned.

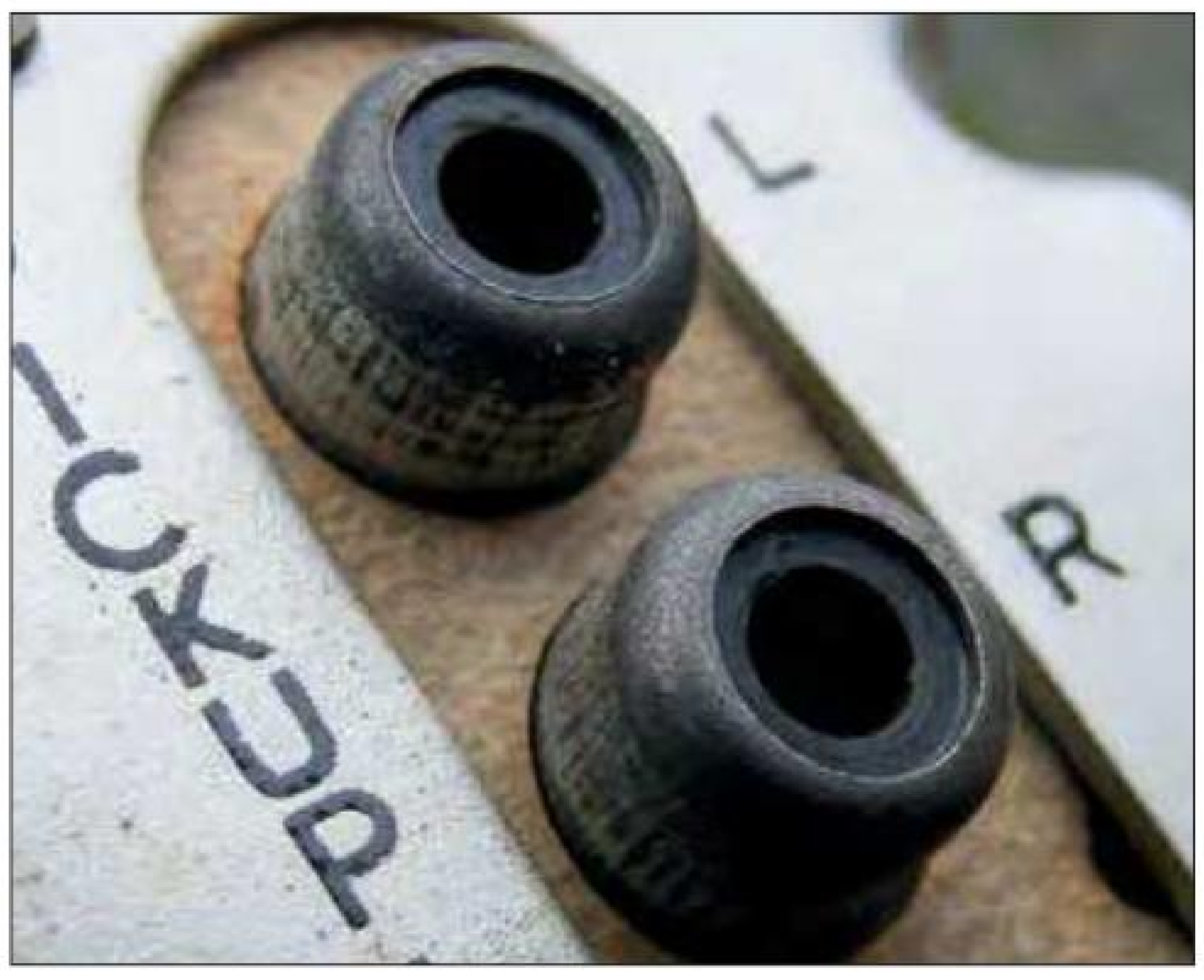


Fig.25. Sometimes a good scrub with a brass brush and wire wool can get contacts usable again.

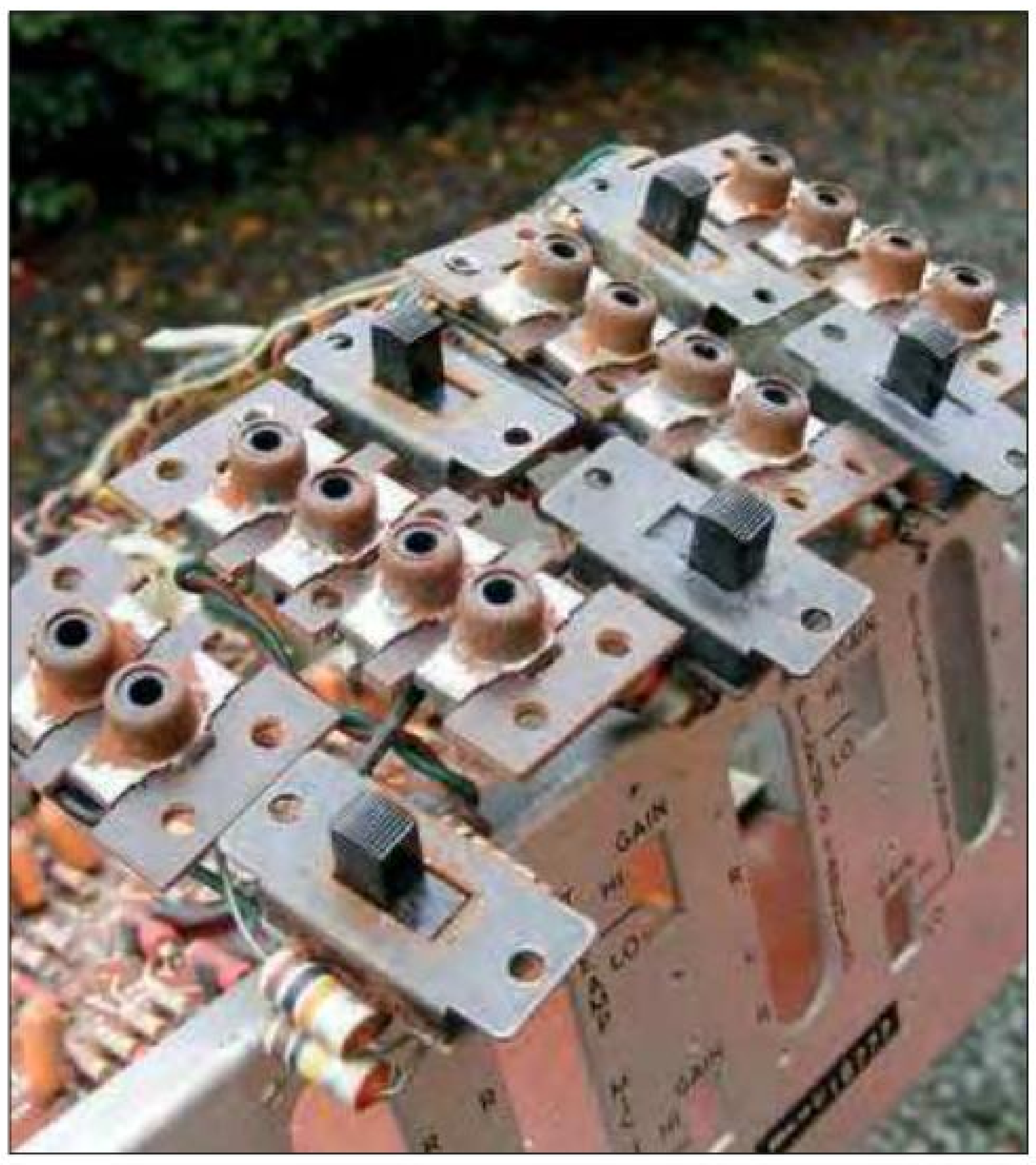


Fig.26. Radical excision of the input assembly was deemed necessary on the eBay amp.

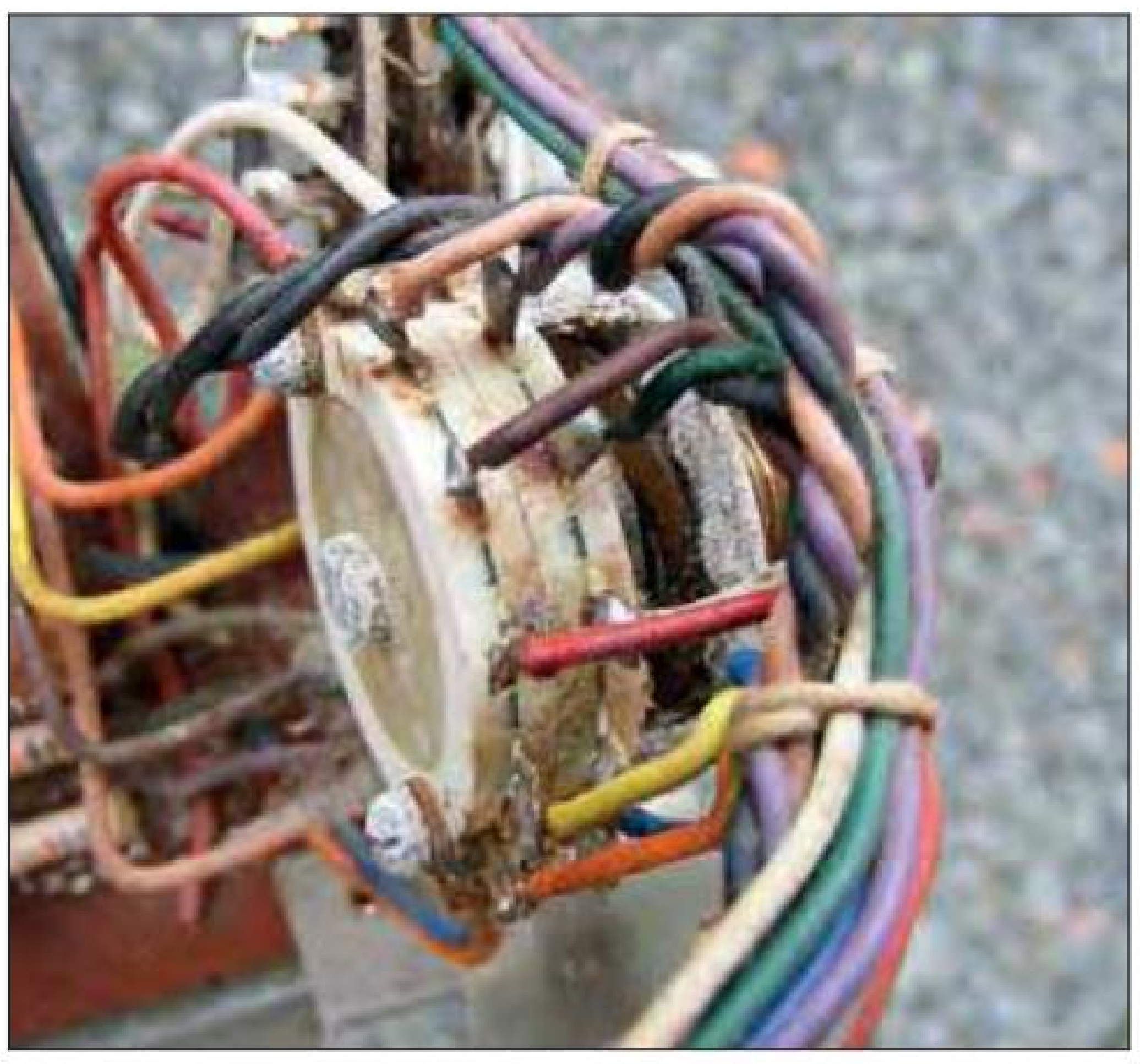


Fig.27. Input selector switch looked so corroded that I chopped it out. In fact, I didn't need to. It was sealed and the contacts were fine when I opened it up. Next time, I'll test before condemning it because it was a lot of work to replace it.

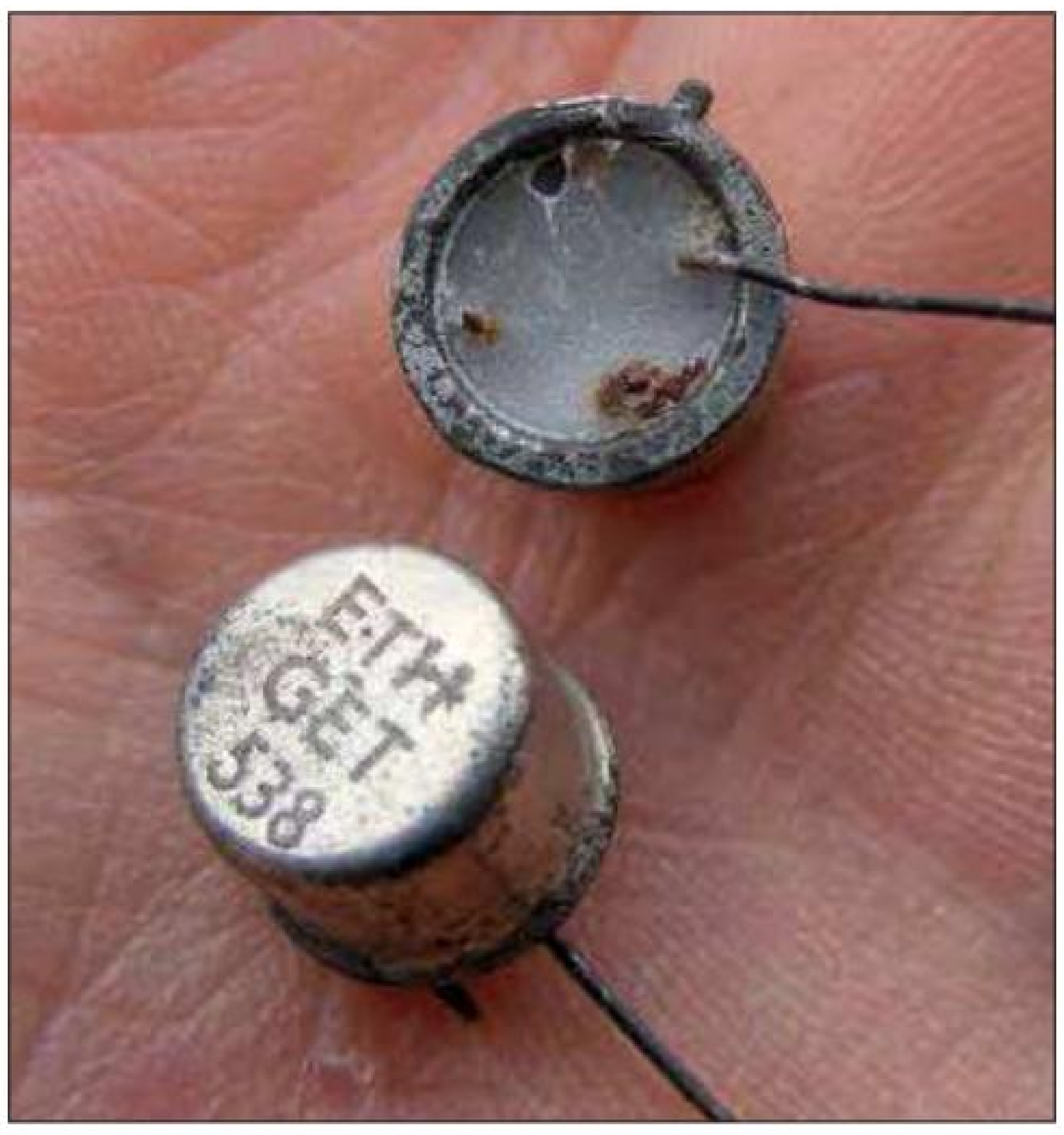


Fig.28. This GET538 driver (T6L/R) transistor's legs had corroded through. This failure also killed its associated output transistor.

the input socket assembly in Fig.26 on the eBay amp. The input selector switch also looked beyond hope, as shown in Fig.27. This is then a good excuse to fit some decent sockets and rationalise the whole input system for greater reliability. I made a version with CD input and aux inputs that went into the tone control input, avoiding the excess gain and noise of the original input stage, which was then permanently wired for phono input.

Germanium transistor issues

Most germanium transistors have thin iron wires to stop soldering heat getting into the device. These are especially prone to corroding right through with spilt acidic drinks, such as red wine. The two GET538s germanium transistors in Fig.28 have lost a couple of wires. The AF118s and AC127Zs were badly corroded as well (Fig.29) but they were still fully functional when tested on the Peak Analyser. This is the sort of thing to expect in old electronics and I always take corroded components out of circuit to test. Normally, it's best just to replace corroded components, because the rusting may carry on. In this case they had to go back in to maintain originality. In fact, later during load testing the right hand AC127Z blew, luckily it took nothing with it.

Speaker connection

The Leak stereo 30 has unique speaker plugs, shown in Fig.30. Fortunately, Andy's came with them. If missing, a standard 4mm banana plug will fit in the big hole and an M3.5 bolt can be screwed into the smaller hole as shown in Fig.31.

Testing

There are a number of components that can be checked with a multimeter before applying power; for example, rectifier diodes and resistors. Most of the latter are carbon composition types which often go high in value as the carbon grains shrink with time. These resistors are hated by most audio engineers – unless they're making fuzz boxes for guitarists. I would take all of them out in critical locations, such as collector loads, and feedback and bias networks to reduce noise and distortion. Resistors can to some extent be tested in-situ, changing any that read higher than their marked value. Any that read significantly lower must have a resistance in parallel and will have to be tested with one end lifted. I found R53L/R and R54L/R had gone high in the power amplifier. Later models had the Erie 'pluggable' types illustrated in Fig.32 which ease assembly, but age more quickly than the traditional wire-ended composition resistors. To aid desoldering, simply crack open the body with side cutters. The thermistors (Fig.33) also use a granular material, and these go high as well. I had one TH2 measure 764Ω when it was meant to be 500Ω. However, in some case readjusting presets should be able to compensate for the drift.

Capacitors

The red Telegraph Condenser Company (TCC) Elkomold electrolytics shown in Fig.34 are often dried-up, going open-circuit or high ESR, and need to be

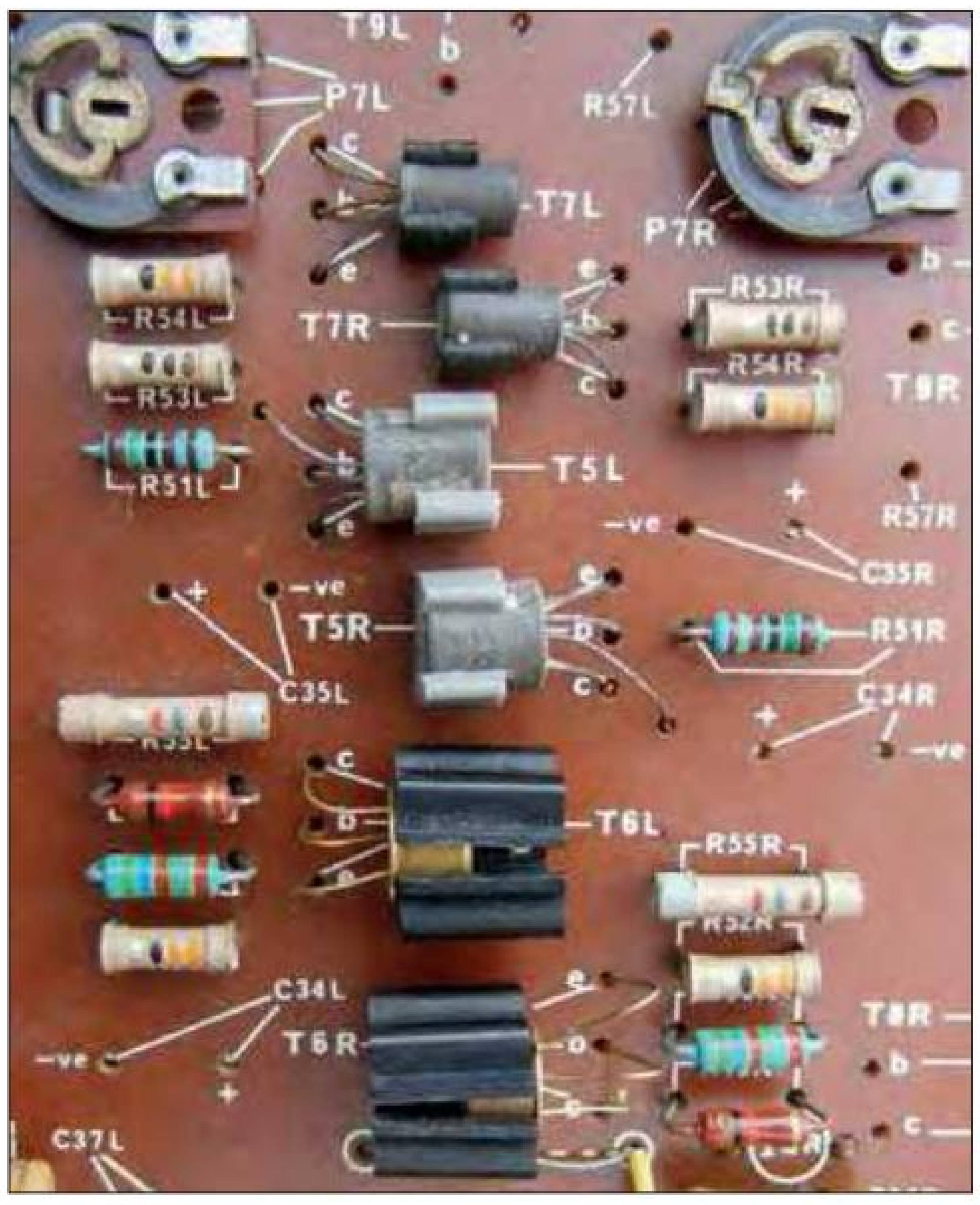


Fig.29. The AF127Z (T7L/R) and AF118 (T5L/R) transistors are difficult to substitute and replace. Note P7L/R which are the quiescent current presets. Set to minimum resistance (anti-clockwise) before powering up.

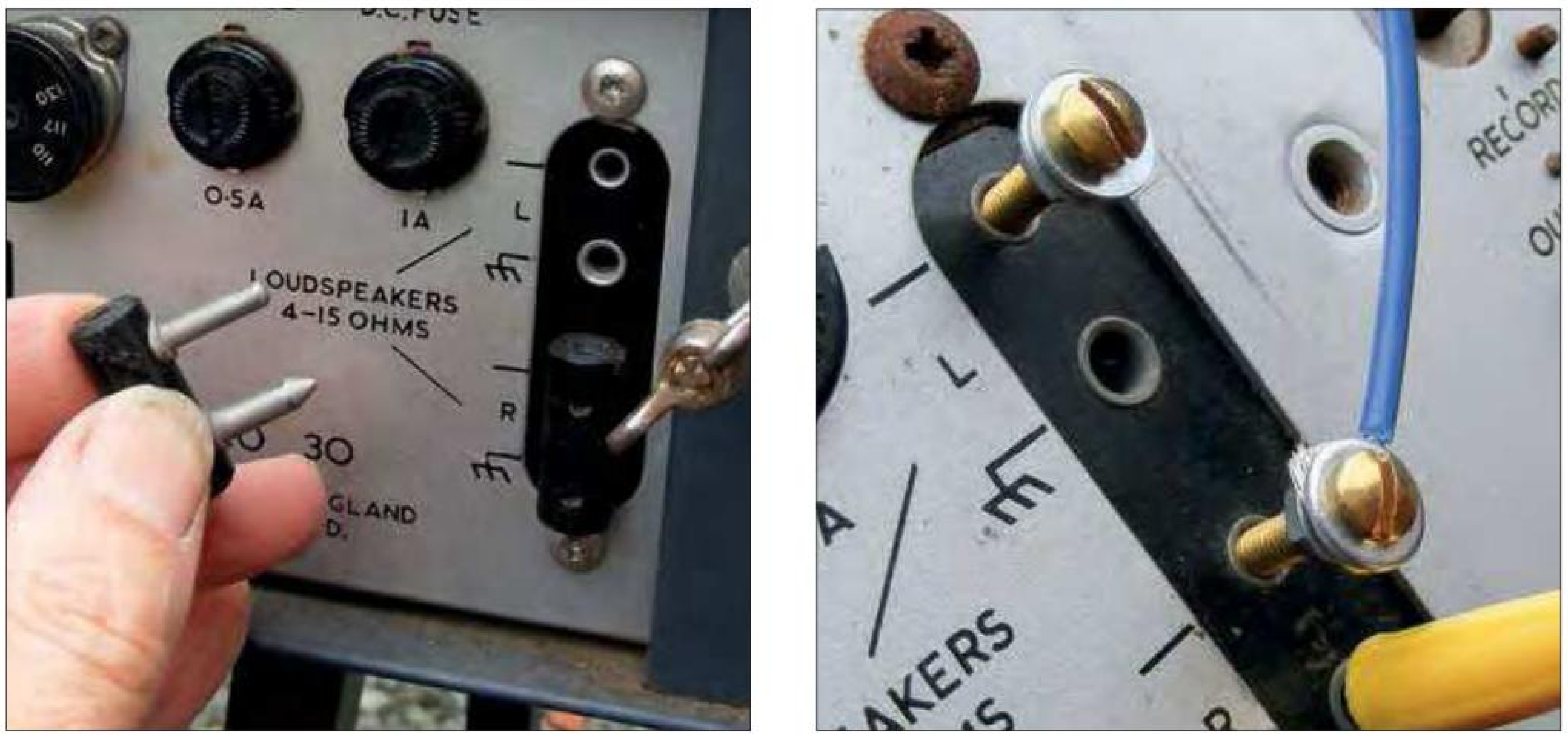


Fig.30. (left) The Stereo 30 had strange speaker plugs. Luckily, this unit had been stored with its plugs; Fig.31. (right) On the eBay amp I had to improvise by screwing an M3.5 bolt into the smaller hole.

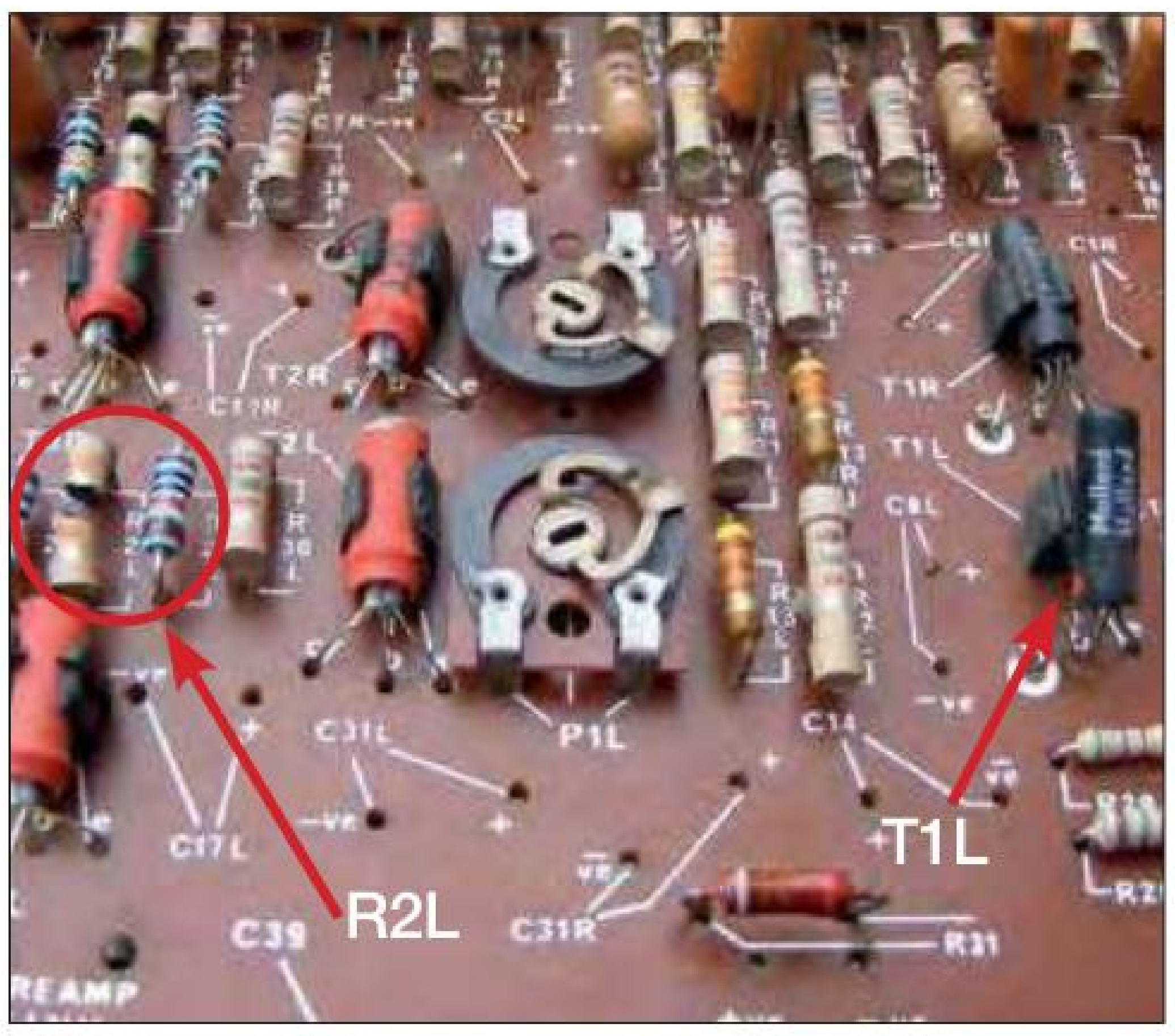


Fig.32. Unfortunately, some old equipment is a forest of Erie pluggable carbon composition resistors. All had increased in value by 30%. Even the 5% grade ones on the RIAA network. When I have to remove a lot of them, I crack them in half and de-solder one lead-out at a time. (See R2L and also note T1L, the AC107 transistor in a black SO-2 glass package). Note also the presets (P1L) for adjusting the pre-amp DC point.

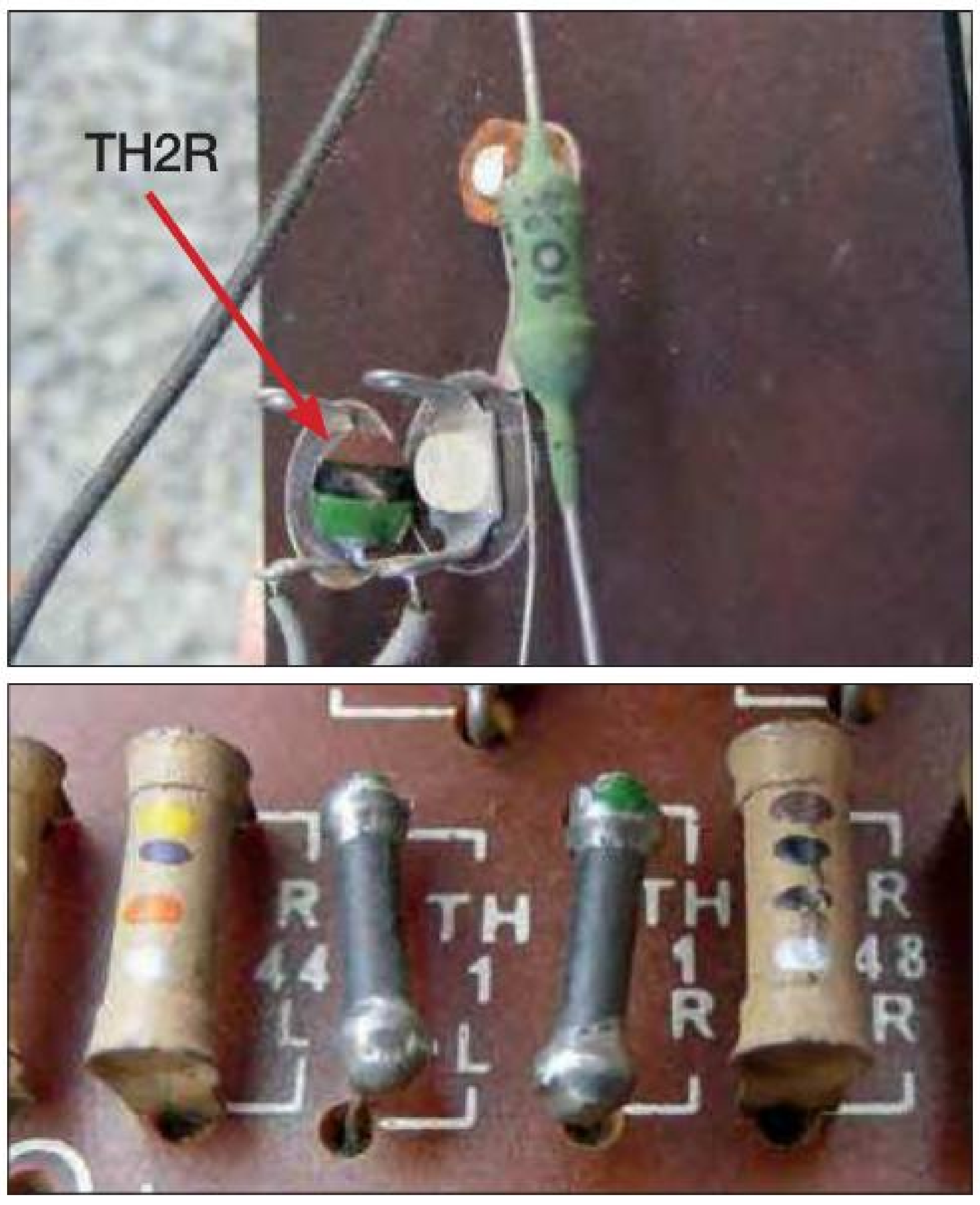


Fig.33. (top) a) The part on the left is a thermistor TH2R to stabilise the quiescent current in the output stage. They go high, but are usually reliable; (bottom) b) TH1L/R, the DC point stabilising thermistors on the power amplifier input stage.

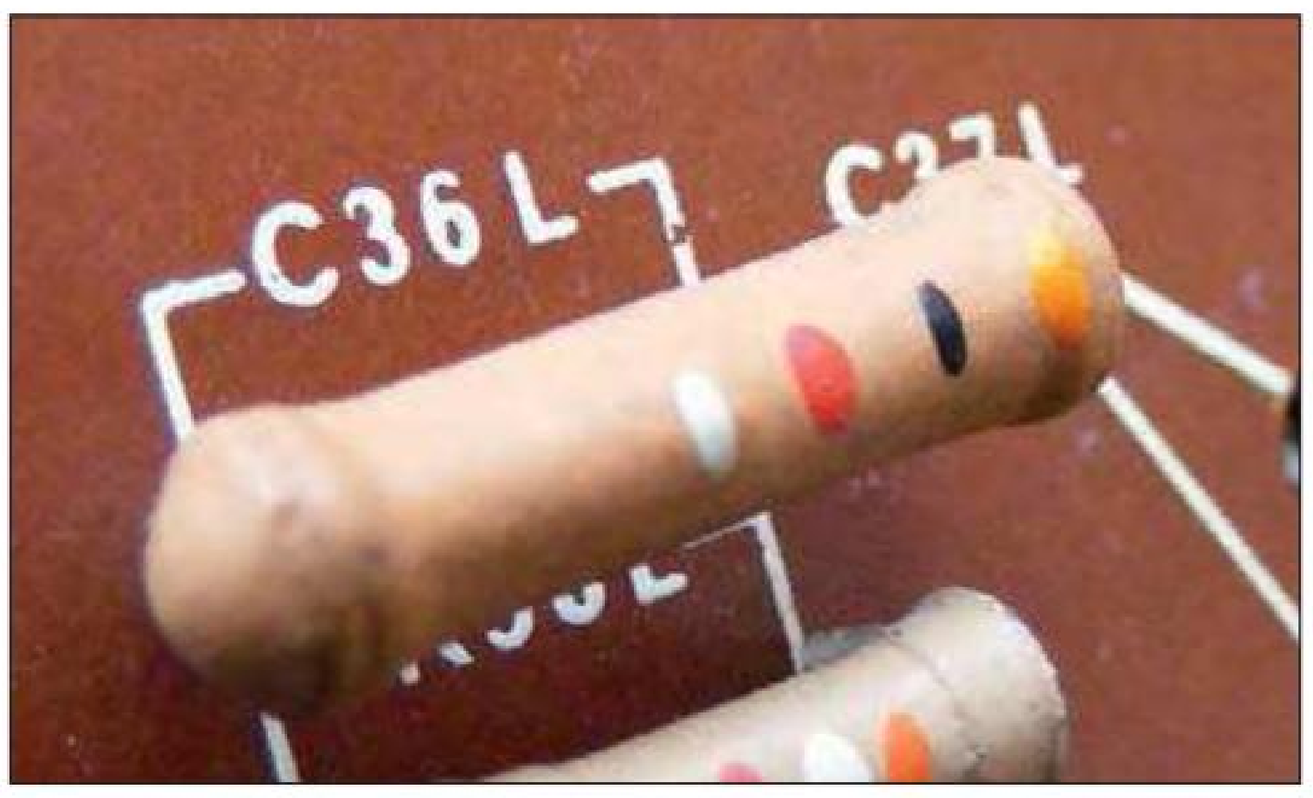


Fig.35. The Erie tubular ceramic capacitors are reliable. They have unusual colour coding. This one is the feedback capacitor C36L and is 3000pF. The white band represents ±10% tolerance.

replaced. Given their plastic cases and strange rivetted connections it's amazing any worked at all. All of these capacitors' positions were marked on the trackside of the PCB to enable testing with the Peak ESR meter. Ten were found to be faulty. If you don't have an ESR meter, just take all of them out. In general, I don't normally believe in 're-capping' (ie, removing and replacing all electrolytic capacitors), it's wasteful, but here it's justified. If some appear high in value, remember that the initial tolerance was –20/+100%. The non-polarised capacitors were mainly SRC (Stability Radio Company) polyester-foil capacitors. These are similar to the Mullard 'mustard cap' C296 series and are very reliable. The remainder of the capacitors were Erie tubular ceramics, such as the 3nF feedback capacitor, which are also reliable. These have unusual colour coding, as shown in Fig.35. If you have old equipment with the blue Mullard/Philips axial electrolytics, these are usually fine, and Vishay and Kemet still make equivalent long-life axial types.

Light Dependent Resistors

Mullard Ltd., Mullard House, Torrington Place, London, W.C.1.

This is a new and inexpensive light dependent resistor, type RPY30, which is ideal where a light source is required to tr an electric current. The RPY30 is photo-conductive cadmium sulphide in a clear plastic encapsulation. The m applied voltage is 150V at an amb temperat ange of –30°C to The re is 10 megohm dark resist 00 ohms lig ance The con ower dissipation milliwatts.

PE
MA

ature Electrolytic Capacitors

Telegraph Condenser Co. Ltd., North Acton, W.3.

new range of capacitors which should be very ular with constructors is the "Elkomold" miniature

Fig.34.These old TCC Elkomould electrolytic capacitors have all dried up. They were the latest thing in *PE*, March 1965 p.359.

Powering up

All Hi-Fi amplifiers need the same standard sequence of checks, strictly in the following order:

- Visual inspection, including earth safety check
- Power supply isolation and voltage check
- Power amplifier check
- Preamplifier check (there is a link to isolate the pre-amp power supply under the board if necessary).

AC check

First check the continuity from the earth pin on the mains lead to the chassis. This is to ensure the mains AC fuse blows if there is a short from the live to the metalwork. When first turning on an old piece of electronics it is essential to limit the input current. I did this by removing the mains fuse and soldering a 2.2kΩ 5W wire-wound resistor across it, as shown in Fig.36. The DC fuse (in the DC power rail) was also removed. This was to enable the power supply to be checked and reform the main smoothing capacitors slowly. Any problems with the mains transformer or the metal 'top-hat' Semics 20A5 rectifiers will also be exposed at this stage and no damage will occur, the resistor taking the strain. If it starts smoking you know there is a problem. Once all is well, the fuse can be replaced and the resistor taken out.

I prefer to do this start-up test procedure with resistors. The service books say use a variac (a variable mains auto-transformer). This works fine with valve amplifiers, but transistor amplifiers can suddenly 'snap-on' as the voltage is increased, taking a massive current and thereby destroying themselves. Also, a variac is quite an unusual piece of equipment, which most people don't have.

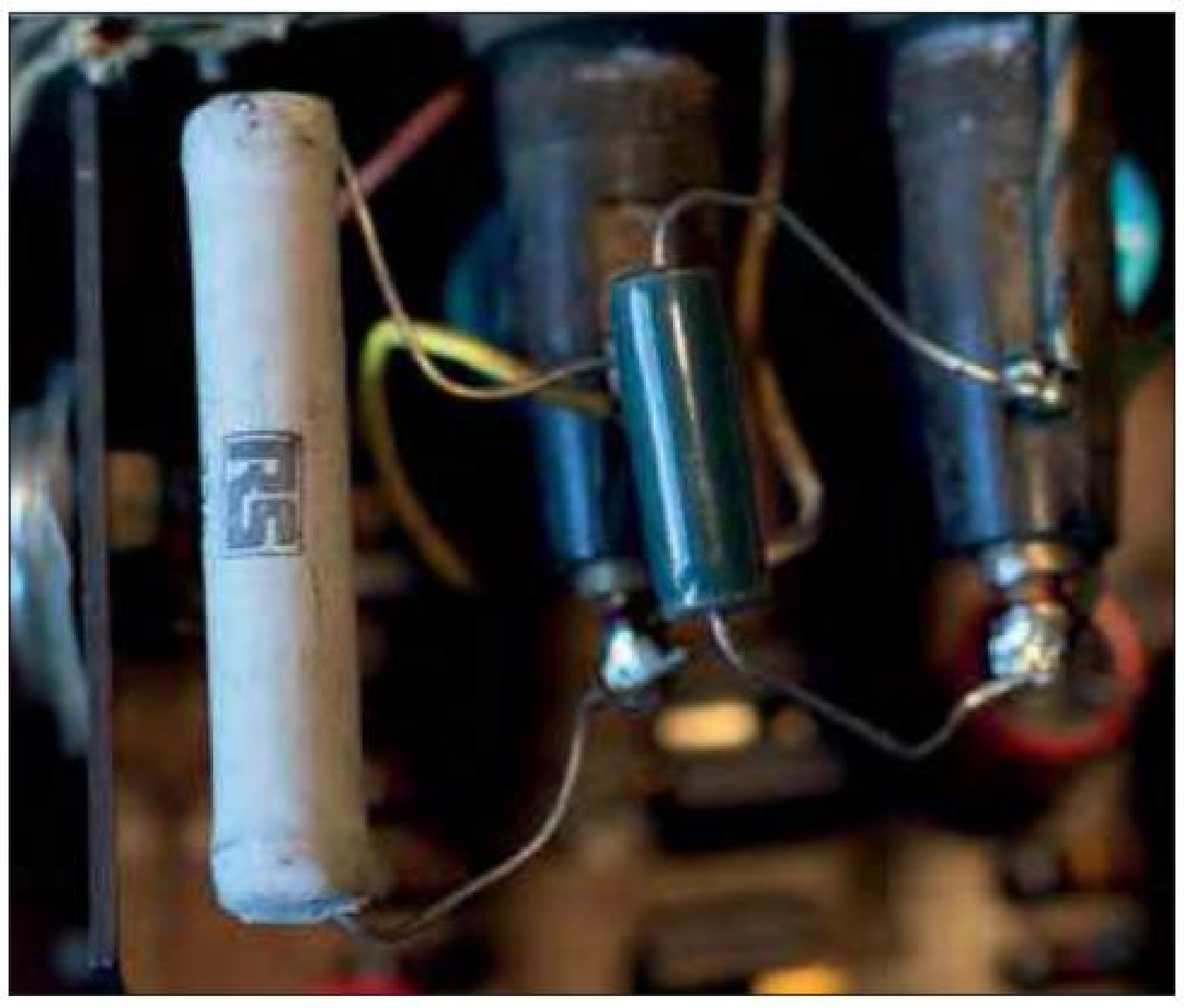


Fig.36. 2.2kΩ 7W vitreous wire-wound resistor across the mains fuse holder to limit current on first turn on. Take care, exposed mains! Also note the silicone-coated 100Ω current-limiting resistor ('RS') in place of the DC fuse for when power is first applied to the power amplifier.

DC check

We do the same trick again, but this time putting a 100Ω 5W resistor across the DC fuse, shown also in Fig.36. If it gets hot turn it off and check for faults.

Next month

In the next installment we'll complete the restoration and look at a few optional amplifier upgrades.

WARNING!

When restoring electronic equipment, do ensure you work with:

- **Eye protection**
- **Fume extraction**
- **Safe wiring/earthing**

These are not nice-to-have optional extras – you must follow all safety guidelines to protect yourself and those around you.

Practical Electronics PCB SERVICE

PROJECT	CODE	PRICE
MAY 2021		
7-Band Equaliser (Mono)	01104201	£8.95
7-Band Equaliser (Stereo)	01104202	£10.95
Car Altimeter	05105201	£7.95
APRIL 2021		
Reflow Oven – DSP Active Crossover (CPU)	01106193	£19.95
Reflow Oven – DSP Active Crossover (Front panel)	01106195	
Reflow Oven – DSP Active Crossover (LCD)	01106196	
Frequency Reference Signal Distributor	CSE200103	£8.95
MARCH 2021		
Nutube Guitar Effects Pedal	01102201	£12.95
Programmable Thermal Regulator (Peltier Interface)	21109181	£18.95
Programmable Thermal Regulator (Peltier Driver)	21109182	
Tunable HF Preamp	CSE190502	£8.95
FEBRUARY 2021		
4G Remote Monitoring	27111191	£9.95
JANUARY 2021		
Nutube Valve Preamplifier	01112191	£12.95
Arduino DCC Controller	09207181	£10.95
DECEMBER 2020		
Pseudo-Random Sequence Generator	16106191	£7.95
Clever Charger	14107191	£11.95
PE Theremin Amplifier	AO-1220-01	£7.95
NOVEMBER 2020		
LED Christmas Tree (1 off)	16107181-1	£6.95
LED Christmas Tree (4 off)	16107181-2	£14.95
LED Christmas Tree (12 off)	16107181-3	£24.95
LED Christmas Tree (20 off)	16107181-4	£34.95
USB/SPI Interface Board	16107182	£5.95
45V/8A Power Supply PCB *plus* acrylic spacer	18111181	£14.95
45V/8A Power Supply front panel five-way display bezel	18111181-BZ	£3.95
Five-way LCD Panel Meter/Display	18111182	£7.95
OCTOBER 2020		
Digital Audio Millivoltmeter	04108191	£8.95
Precision Signal Amplifier	04107191	£6.95
SEPTEMBER 2020		
PE Theremin PSU	AO-0920-01	£5.95
PE Theremin PSU transformer	AO-0920-02	£7.95
Micromite Explore-28	07108191	£5.95
Ultrabrite LED Driver	16109191	£5.95
AUGUST 2020		
Micromite LCD BackPack V3	07106191	£9.95
Steering Wheel Audio Button to Infrared Adaptor	05105191	£7.95
JULY 2020		
AM/FM/CW Scanning HF/VHF RF Signal Generator	04106191	£11.95
Speech Synthesiser with the Raspberry Pi Zero	01106191	£5.95
PE Mini-organ PCB	AO-0720-01	£14.95
PE Mini-organ selected parts	AO-0720-02	£8.95
High-current Solid-state 12V Battery Isolator – control	05106191	£6.95
High-current Solid-state 12V Battery Isolator FET (2oz)	05106192	£9.95
JUNE 2020		
Arduino breakout board – 3.5-inch LCD Display	24111181	£6.95
Six-input Audio Selector main board	01110191	£10.95
Six-input Audio Selector switch panel board	01110192	

PROJECT	CODE	PRICE
MAY 2020		
Ultra-low-distortion Preamplifier Input Selector	01111112	£11.25
Ultra-low-distortion Preamplifier pushbutton Input Selector	01111113	
Universal Regulator	18103111	£7.95
433MHz Wireless Data Repeater	15004191	£8.50
Bridge-mode Adaptor for Amplifier	01105191	£7.95
iCEstick VGA Terminal	02103191	£4.95
Analogue noise with tilt control	AO-0520-01	£7.95
Audio Spectrum Analyser	PM-0520-01	£8.95
APRIL 2020		
Flip-dot Display black coil board	19111181	£14.95
Flip-dot Display black pixels	19111182	
Flip-dot Display black frame	19111183	
Flip-dot Display green driver board	19111184	
MARCH 2020		
Diode Curve Plotter	04112181	£10.95
Steam Train Whistle / Diesel Horn Sound Generator	09106181	£8.50
Universal Passive Crossover (one off)	UPC0320	£12.50
FEBRUARY 2020		
Motion-Sensing 12V Power Switch	05102191	£5.95
USB Keyboard / Mouse Adaptor	24311181	£8.50
DSP Active Crossover (ADC)	01106191	£29.95
DSP Active Crossover (DAC) ×2	01106192	
DSP Active Crossover (CPU)	01106193	
DSP Active Crossover (Power/routing)	01106194	
DSP Active Crossover (Front panel)	01106195	
DSP Active Crossover (LCD)	01106196	
JANUARY 2020		
Isolated Serial Link	24107181	£8.50
DECEMBER 2019		
Extremely Sensitive Magnetometer	04101011	£16.75
Four-channel High-current DC Fan and Pump Controller	05108181	£8.75
Useless Box	08111181	£11.50
NOVEMBER 2019		
Tinnitus & Insomnia Killer (Jaycar case – see text)	01110181	£8.75
Tinnitus & Insomnia Killer (Altronics case – see text)	01110182	£8.75
OCTOBER 2019		
Programmable GPS-synced Frequency Reference	04107181	£11.50
Digital Command Control Programmer for Decoders	09107181	£9.95
Opto-isolated Mains Relay (main board)	10107181	£11.50
Opto-isolated Mains Relay (2 × terminal extension board)	10107182	
AUGUST 2019		
Brainwave Monitor	25108181	£12.90
Super Digital Sound Effects Module	01107181	£6.95
Watchdog Alarm	03107181	£8.00
PE Theremin (three boards: pitch, volume, VCA)	PETX0819	£19.50
PE Theremin component pack (see p.56, August 2019)	PETY0819	£15.00
JULY 2019		
Full-wave 10A Universal Motor Speed Controller	10102181	£12.90
Recurring Event Reminder	19107181	£8.00
Temperature Switch Mk2	05105181	£10.45
JUNE 2019		
Arduino-based LC Meter	04106181	£8.00
USB Flexitimer	19106181	£10.45

PCBs for most recent *PE*/*EPE* constructional projects are available. From the July 2013 issue onwards, PCBs with eight-digit codes have silk screen overlays and, where applicable, are double-sided, have plated-through holes, and solder mask. They are similar to photos in the project articles. Earlier PCBs are likely to be more basic and may not include silk screen overlay, be single-sided, lack plated-through holes and solder mask.

Always check price and availability in the latest issue or online. A large number of older boards are listed for ordering on our website.

In most cases we do not supply kits or components for our projects. For older projects it is important to check the availability of all components before purchasing PCBs.

Back issues of articles are available – see Back Issues page for details.

Double-sided | plated-through holes | solder mask

PROJECT	CODE	PRICE
MAY 2019		
2× 12V Battery Balancer	14106181	£5.60
Deluxe Frequency Switch	05104181	£10.45
USB Port Protector	07105181	£5.60
APRIL 2019		
Heater Controller	10104181	£14.00
MARCH 2019		
10-LED Bargraph Main Board	04101181	£11.25
+Processing Board	04101182	£8.60
FEBRUARY 2019		
1.5kW Induction Motor Speed Controller	10105122	£35.00
NOVEMBER 2018		
Super-7 AM Radio Receiver	06111171	£27.50
OCTOBER 2018		
6GHz+ Touchscreen Frequency Counter	04110171	£12.88
Two 230VAC MainsTimers	10108161 10108162	£12.88
SEPTEMBER 2018		
3-Way Active Crossover	01108171	£22.60
Ultra-low-voltage Mini LED Flasher	16110161	£5.60
AUGUST 2018		
Universal Temperature Alarm	03105161	£7.05
Power Supply For Battery-Operated Valve Radios	18108171 18108172 18108173 18108174	£27.50
JULY 2018		
Touchscreen Appliance Energy Meter – Part 1	04116061	£17.75
Automotive Sensor Modifier	05111161	£12.88
JUNE 2018		
High Performance 10-Octave Stereo Graphic Equaliser	01105171	£15.30
MAY 2018		
High Performance RF Prescaler	04112162	£10.45
Micromite BackPack V2	07104171	£8.45
Microbridge	24104171	£5.60
APRIL 2018		
Spring Reverberation Unit	01104171	£13.95
DDS Sig Gen Lid	Black	£8.05
DDS Sig Gen Lid	Blue	£7.05
DDS Sig Gen Lid	Clear	£8.05
MARCH 2018		
Stationmaster Main Board + Controller Board	09103171 09103172	£17.75
SC200 Amplifier Module – Power Supply	01109111	£16.45
FEBRUARY 2018		
GPS-Synchronised Analogue Clock Driver	04202171	£12.88
High-Power DC Motor Speed Controller – Part 2		
+ Control Board	11112161	£12.88
+ Power Board	11112162	£15.30
JANUARY 2018		
High-Power DC Motor Speed Controller – Part 1	11112161	£12.88
Build the SC200 Amplifier Module	01108161	£12.88

PROJECT	CODE	PRICE
DECEMBER 2017		
Precision Voltage and Current Reference – Part 2	04110161	£15.35
NOVEMBER 2017		
50A Battery Charger Controller	11111161	£12.88
Micropower LED Flasher (45 × 47mm)	16109161	£8.00
(36 × 13mm)	16109162	£5.60
Phono Input Converter	01111161	£8.00
SEPTEMBER 2017		
Compact 8-Digit Frequency Meter	04105161	£12.88
AUGUST 2017		
Micromite-Based Touch-screen Boat Computer GPS	07102122	£10.45
Fridge/Freezer Alarm	03104161	£8.00
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Jim Gatenby

PYTHON CODING ON THE BBC MICRO:BIT

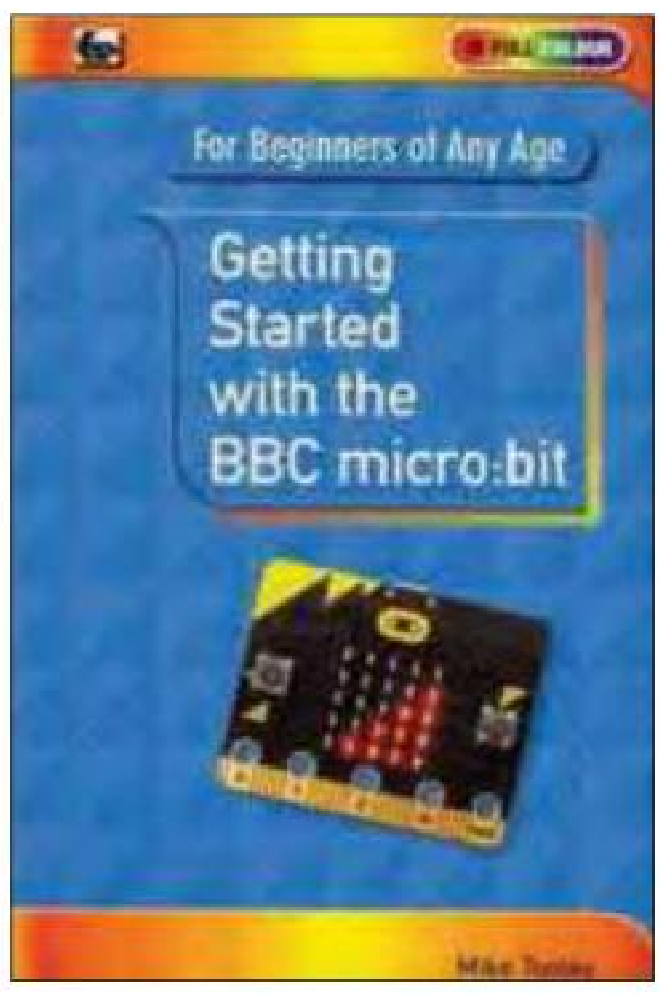
Jim Gatenby

Python is the leading programming language, easy to learn and widely used by professional programmers. This book uses MicroPython, a version of Python adapted for the BBC Micro:bit.

Among the many topics covered are: main features of the BBC micro:bit including a simulation in a web browser screen; various levels of programming languages; Mu Editor for writing, saving and retrieving programs, with sample programs and practice exercises; REPL, an interactive program for quickly testing lines of code; scrolling messages, creating and animating images on the micro:bit's LEDs; playing and creating music, sounds and synthesized speech; using the on-board accelerometer to detect movement of the micro:bit on three axes; glossary of computing terms.

This book is written using plain English, avoids technical jargon wherever possible and covers many of the coding instructions and methods which are common to most programming languages. It should be helpful to beginners of any age, whether planning a career in computing or writing code as an enjoyable hobby.

118 Pages **Order code PYTH MBIT** £7.99



GETTING STARTED WITH THE BBC MICRO:BIT

Mike Tooley

Not just an educational resource for teaching youngsters coding, the BBC micro:bit is a tiny low cost, low-profile ARM-based single-board computer. The board measures 43mm × 52mm but despite its diminutive footprint it has all the features of a fully fledged microcontroller together with a simple LED matrix display, two buttons, an accelerometer and a magnetometer.

Mike Tooley's book will show you how the micro:bit can be used in a wide range of applications from simple domestic gadgets to more complex control systems such as those used for lighting, central heating and security applications. Using Microsoft Code Blocks, the book provides a progressive introduction to coding as well as interfacing with sensors and transducers.

Each chapter concludes with a simple practical project that puts into practice what the reader has learned. The featured projects include an electronic direction finder, frost alarm, reaction tester, battery checker, thermostatic controller and a passive infrared (PIR) security alarm.

No previous coding experience is assumed, making this book ideal for complete beginners as well as those with some previous knowledge. Self-test questions are provided at the end of each chapter, together with answers at the end of the book. So whatever your starting point, this book will take you further along the road to developing and coding your own real-world applications.

108 Pages **Order code BBC MBIT** £7.99

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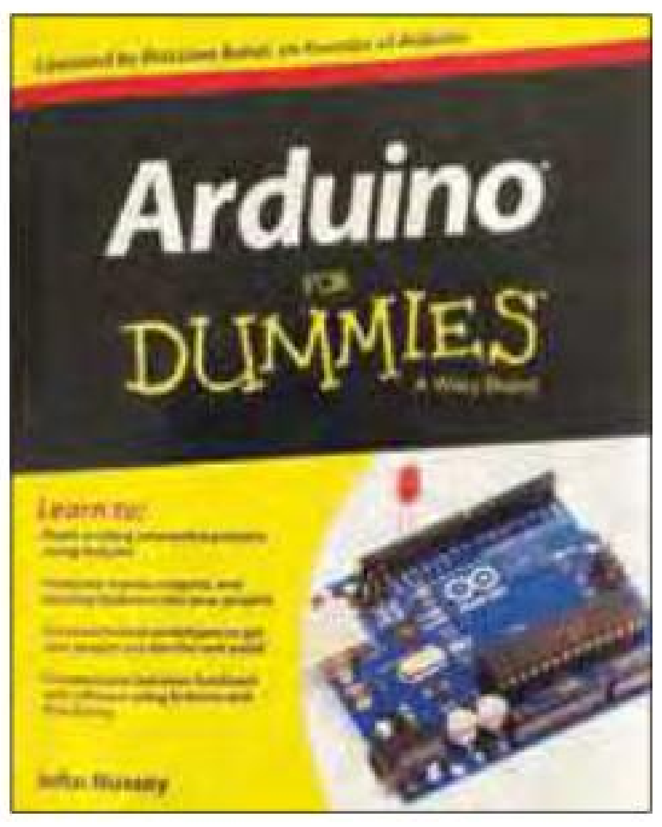
ARDUINO

Teach-In 2016

See opposite for our popular introduction to the Arduino



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John Nussey

Arduino is no ordinary circuit board. Whether you're an artist, a designer, a programmer, or a hobbyist, Arduino lets you learn about and play with electronics. You'll discover how to build a variety of circuits that can sense or control real-world objects, prototype your own product, and even create interactive artwork. This handy guide is exactly what you need to build your own Arduino project – what you make is up to you!

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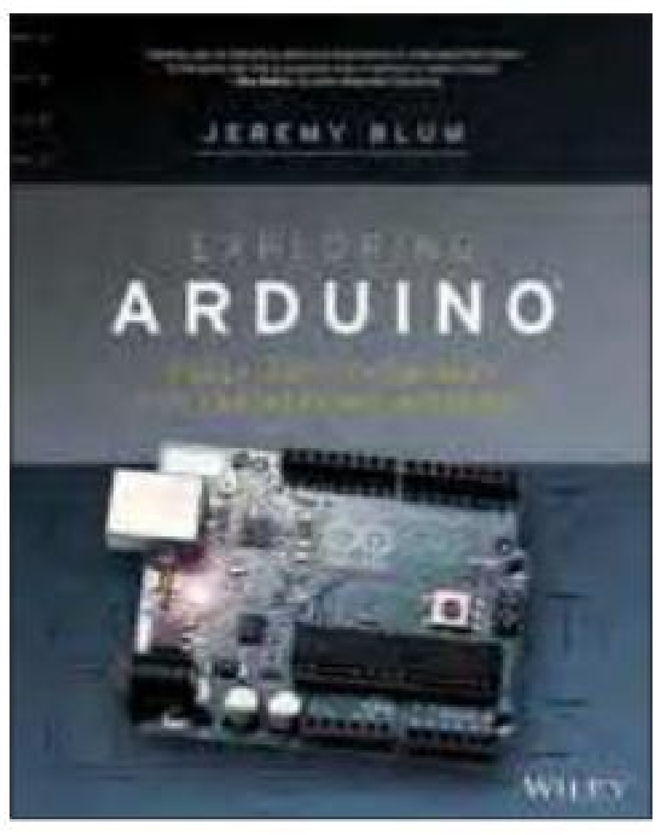

EXPLORING ARDUINO
Jeremy Blum

Arduino can take you anywhere. This book is the roadmap.

Exploring Arduino shows how to use the world's most popular microcontroller to create cool, practical, artistic and educational projects. Through lessons in electrical engineering, programming and human-computer interaction, this book walks you through specific, increasingly complex projects, all the while providing best practices that you can apply to your own projects once you've mastered these. You'll acquire valuable skills – and have a whole lot of fun.

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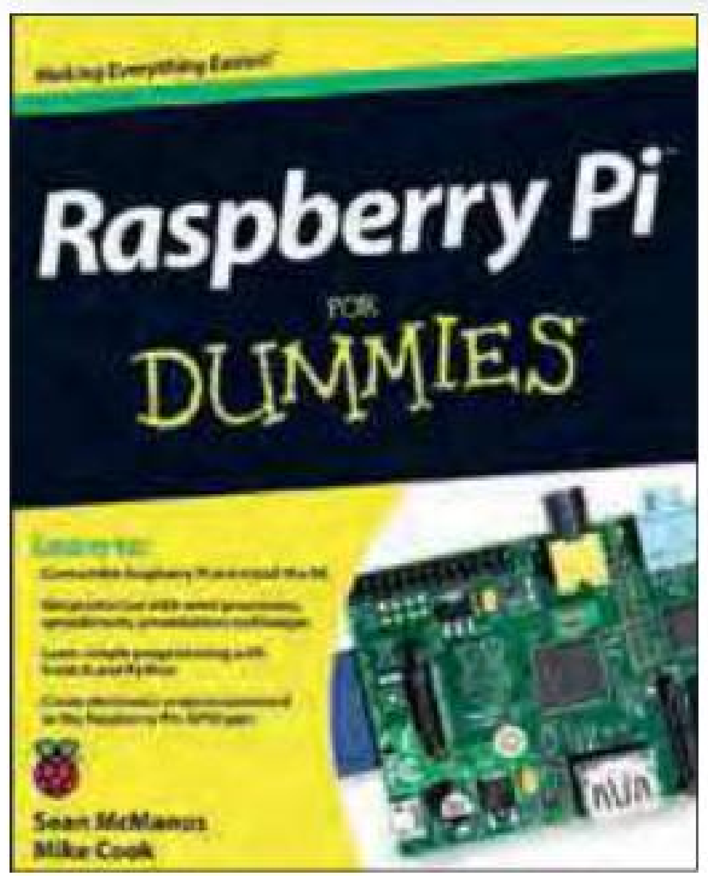

RASPBERRY Pi FOR DUMMIES
Sean McManus and Mike Cook

Write games, compose and play music, even explore electronics – it's easy as Pi! The Raspberry Pi offers a plateful of opportunities, and this great resource guides you step-by-step, from downloading, copying, and installing the software to learning about Linux and finding cool new programs for work, photo editing, and music. You'll discover how to write your own Raspberry Pi programs, create fun games, and much more!

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Mike & Richard Tooley

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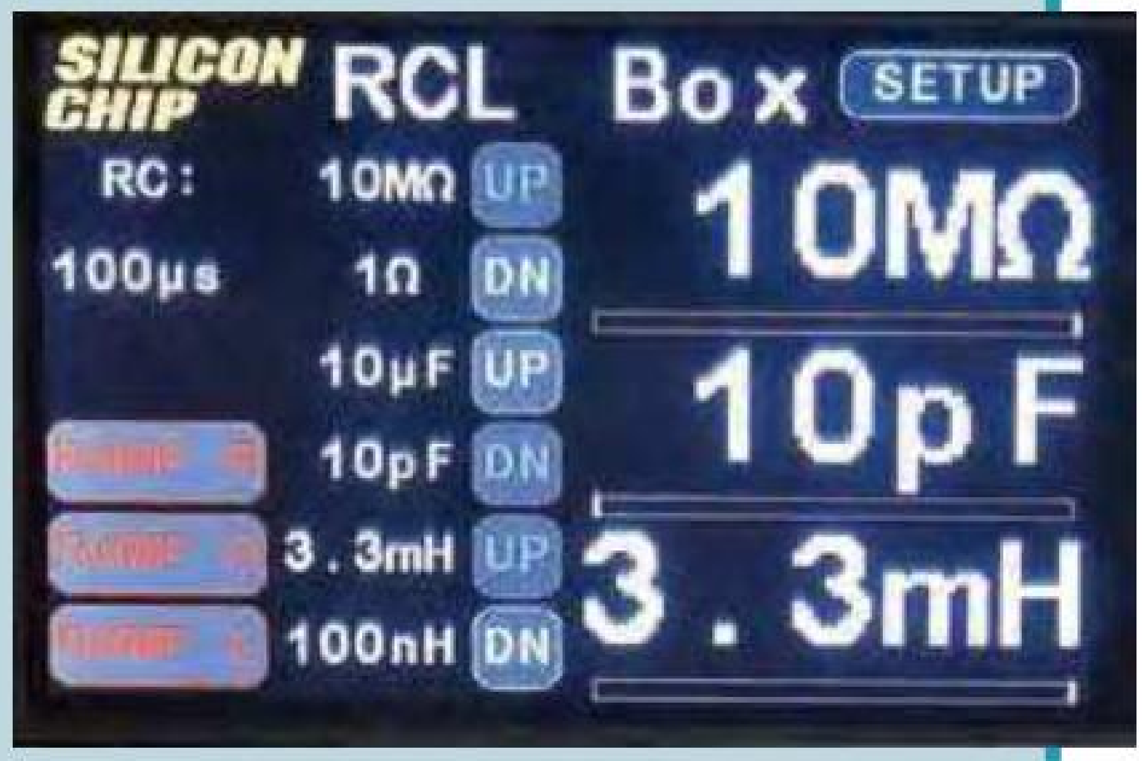

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- **Very low duty cycle to minimise temperature rise.**
- **Continuous measurements.**
- **Single AAA battery (included) with very long battery life.**
- **Gold plated croc clips included.**
- **Can measure forward voltage of LEDs and LED strings too.**

atlas ZEN
model ZEN50
PEAK electronic design ltd
Vz=27.74V @ 15mA
Slope R=53Ω
Zener diode analyser
Zener Voltage
Slope Resistance
Selectable Test Currents
Vz<50V
on - test
scroll - off
warning: not for in-circuit

~~£46.50~~ £39.53
~~£38.75+VAT~~ **with discount!**

LCR45 LCR and Impedance Meter with Auto and Manual modes

Advanced firmware!

The powerful LCR45 meter that not only identifies and measures your passive components (Inductors, Capacitors and Resistors) but also measures complex impedance, magnitude of impedance with phase and admittance too! Auto and Manual test modes allow you to specify the test frequency and component type.

- **Continuous fluid measurements.**
- **Improved measurement resolution: (<0.2µH, <0.2pF).**
- **Test frequencies: DC, 1kHz, 15kHz, 200kHz.**
- **Measure the true impedance of speakers and more.**
- **Great for hobbyists and professionals.**

LCR and impedance meter
PEAK
Inductor 0.310%
L=701.1µH @15kHz
LCR45
on - menu
enter - off
warning: avoid charge/voltages
Complex Impedance
Impedance 200kHz
+25.6 +j155.1Ω

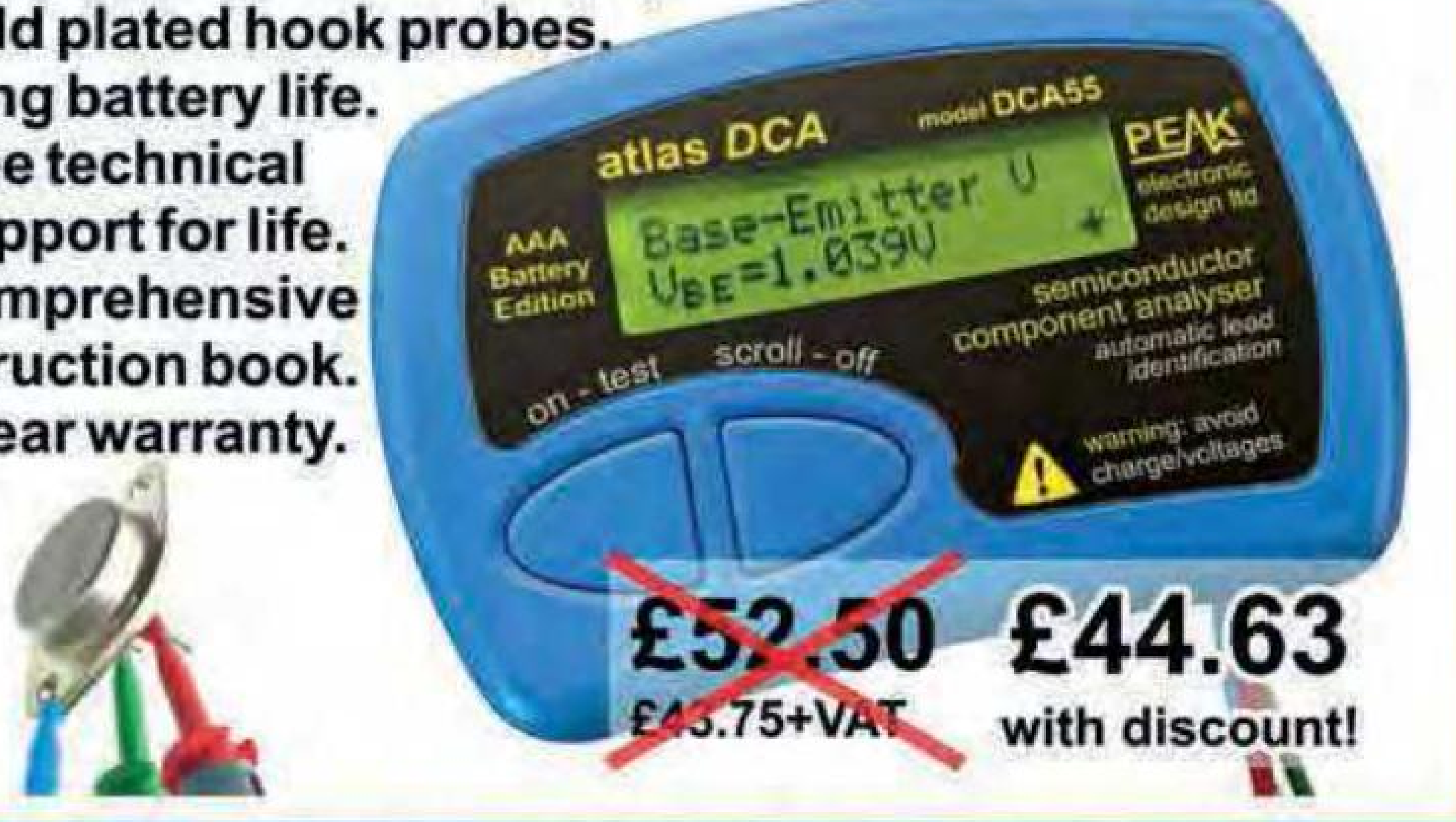
~~£91.50~~ £77.78
~~£76.25+VAT~~ **with discount!**

DCA55 Semiconductor Analyser - Identify your semi's

Now with backlit display and AAA battery!

Connect any way round to identify the type of component and the pinout! Also measures many parameters including transistor gain, base-emitter voltages, MOSFET thresholds, LED voltages etc. Complete with a comprehensive illustrated user guide. Includes an Alkaline battery so you're ready to go straight away.

- **Transistors (including NPN/PNP, darlingtons, Si & Ge).**
- **Measure hFE, V_{BE} and leakage.**
- **Diodes and LEDs. Measure V_F.**
- **MOSFETs. Measure V_{GS}(th).**
- **Gold plated hook probes.**
- **Long battery life.**
- **Free technical support for life.**
- **Comprehensive instruction book.**
- **2 year warranty.**



atlas DCA
model DCA55
PEAK electronic design ltd
AAA Battery Edition
Base-Emitter V
VBE=1.039V
semiconductor component analyser
automatic lead identification
on - test
scroll - off
warning: avoid charge/voltages

~~£52.50~~ £44.63
~~£43.75+VAT~~ **with discount!**

ESR70 Equivalent Series Resistance and Capacitance Meter

Now with backlit display and AAA battery!

The new improved ESR70 is great for identifying capacitors (especially electrolytics) that are suffering from high ESR. ESR is a great indicator of capacitor condition, especially in applications demanding high ripple currents such as reservoir capacitors, SMPSUs, motor capacitors etc. Includes Alkaline AAA battery and a very comprehensive user guide. The ESR70 will even perform a controlled discharge of your caps!

atlas ESR+
model ESR70
PEAK electronic design ltd
Cap = 22.28µF
ESR = 0.48Ω
ESR, low resistance and capacitance meter
+ Audible Alerts
with automatic discharge function
on - test
off

~~£84.00~~ £71.40
~~£70.00+VAT~~ **with discount!**

It's only possible to show summary specifications here. Please ask if you'd like detailed data. Further information is also available on our website. Product price refunded if you're not happy.

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